The ultracold neutron source at the Paul Scherrer Institute and its fundamental physics program

Bernhard Lauss
Ultracold neutron physics group
Paul Scherrer Institute

April 2024

UCN and VCN Source at the Institute of Nuclear Physics, Kazakhstan and their applications

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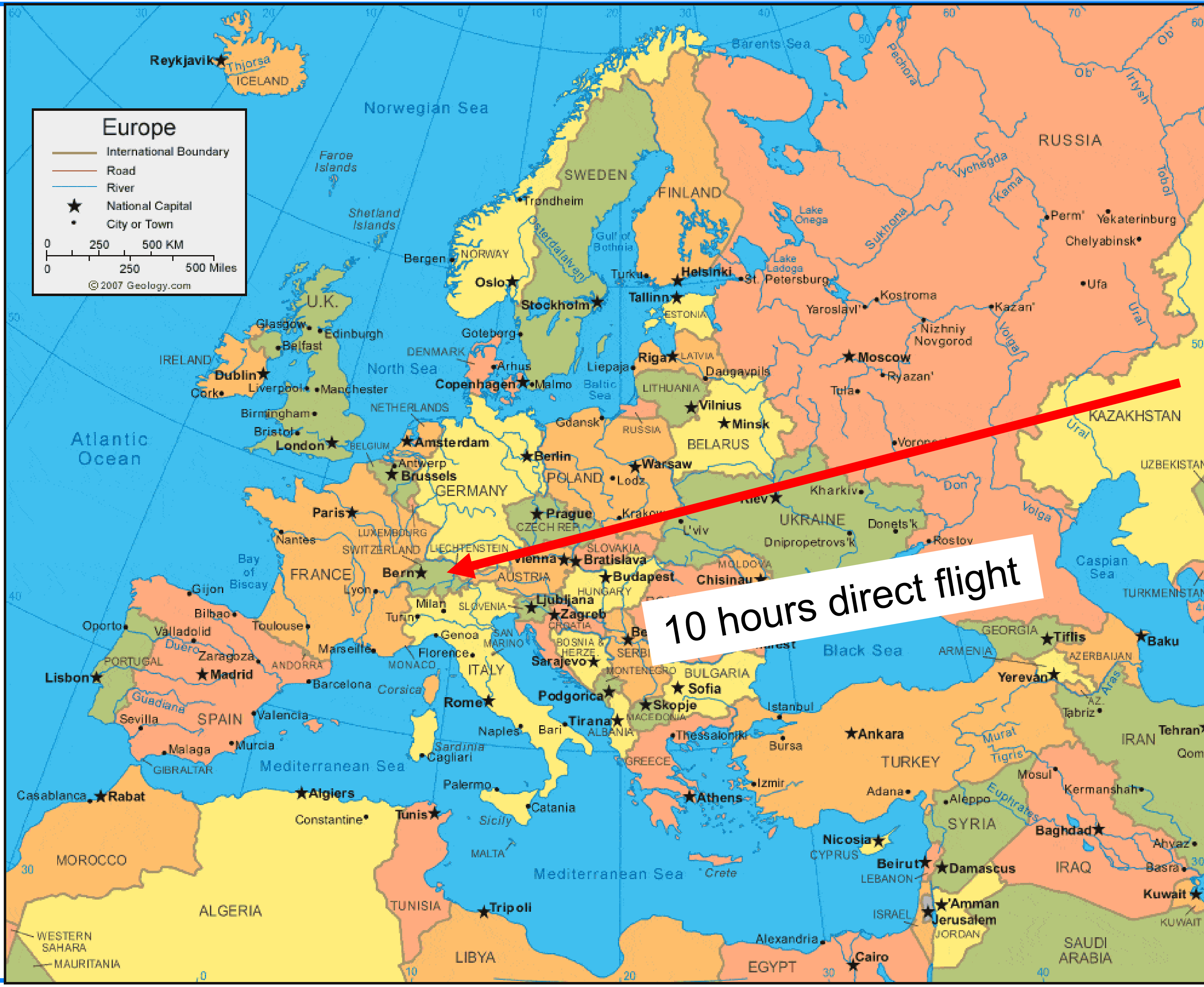
Paul Scherrer Institute - Villigen, Switzerland

Ultra Cold Neutron Source



Paul Scherrer Institute - Villigen, Switzerland

PSI is the largest national lab in Switzerland providing large-scale facilities
- proton accelerator for particle and solid state physics
- Swiss spallation neutron source SINQ
- Swiss Light Source SLS
- SWISSFEL - free electron laser

and

ultracold neutron source UCN

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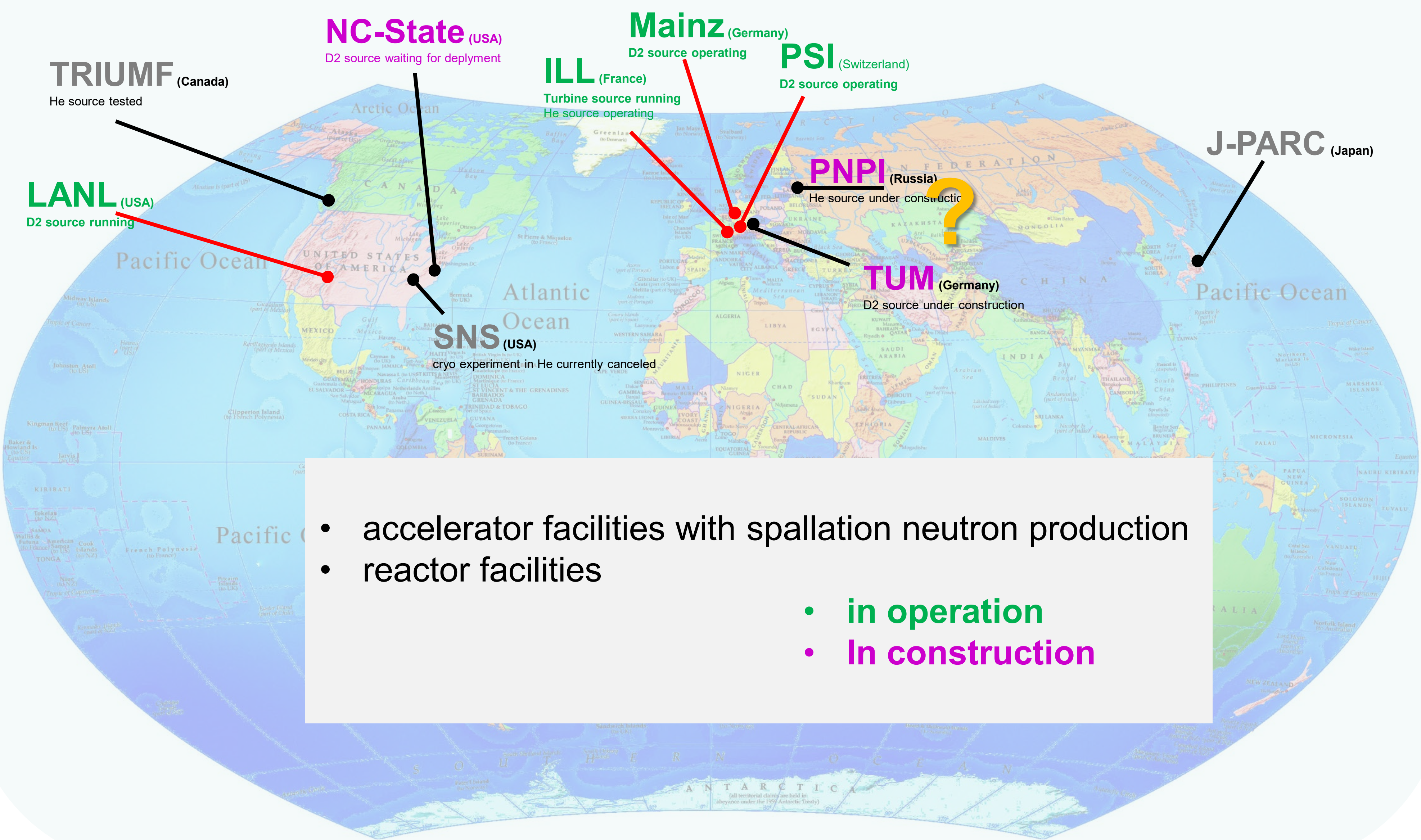
ULTRACOLD NEUTRON SOURCES

Ultra Cold Neutron Source



- accelerator facilities with spallation neutron production
- reactor facilities

  - **in operation**
  - **In construction**

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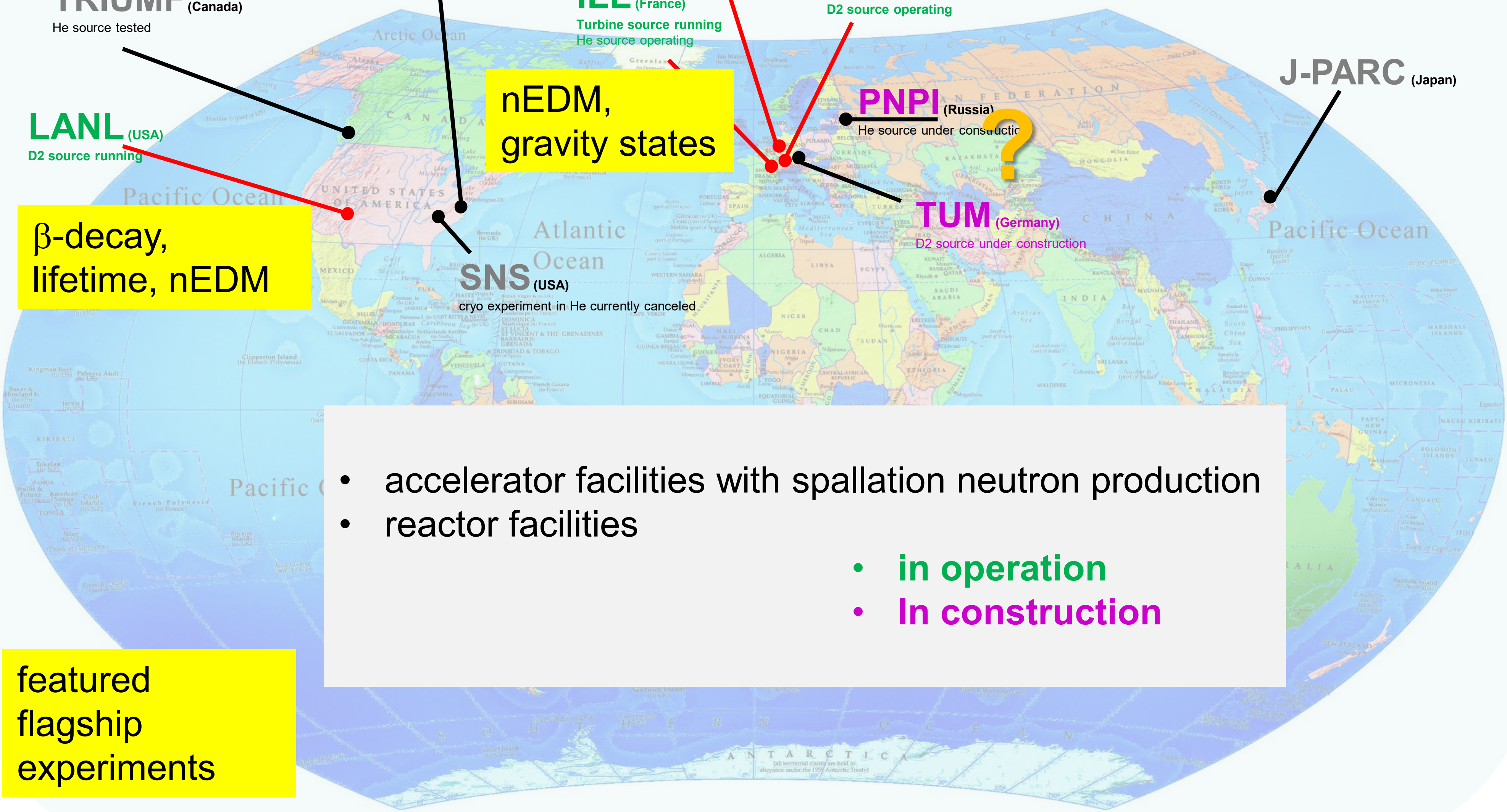
ULTRACOLD NEUTRON SOURCES

Ultra Cold Neutron Source



- accelerator facilities with spallation neutron production
- reactor facilities

- **in operation**
- **In construction**

featured flagship experiments

Time-scale of effort at PSI

UCN source Letter of intent

UCN source proposal
nEDM proposal

Start UCN
source operation

First nEDM
result published

1998 2000 2011 2020

n2EDM
τSPECT

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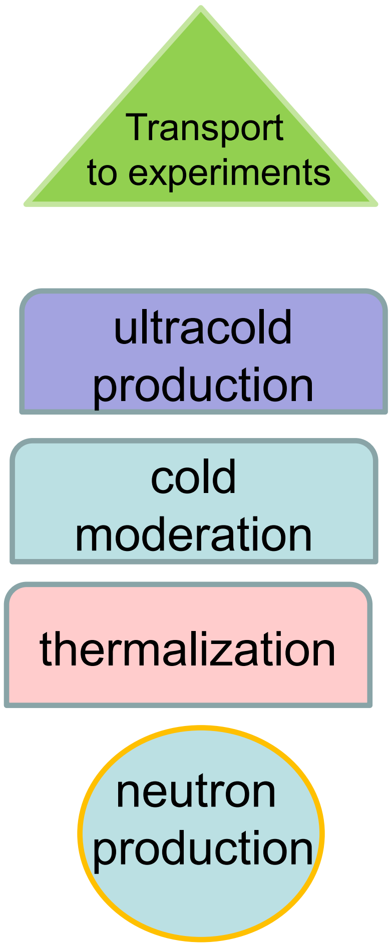
Basic components of operating UCN sources



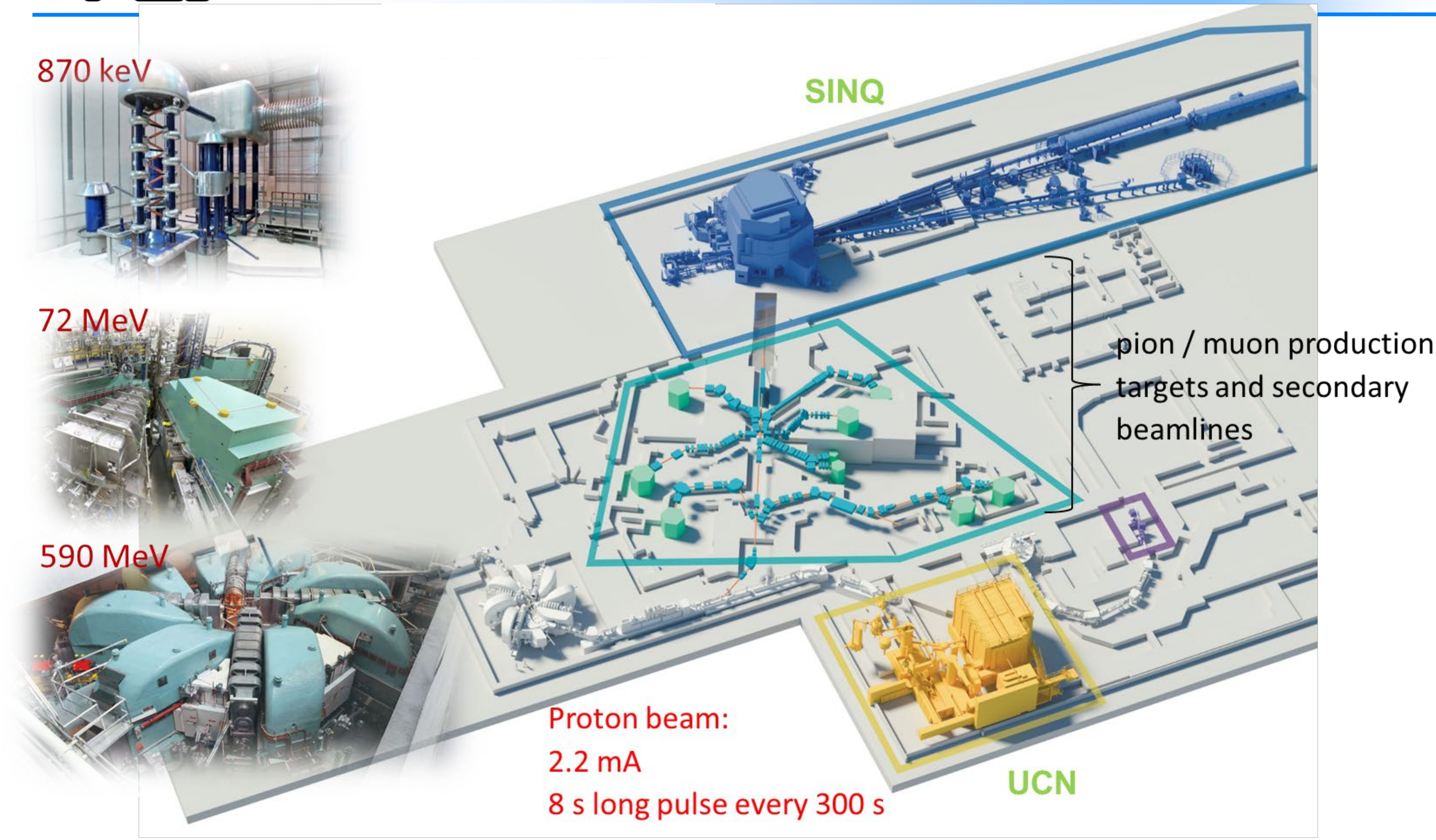
D2

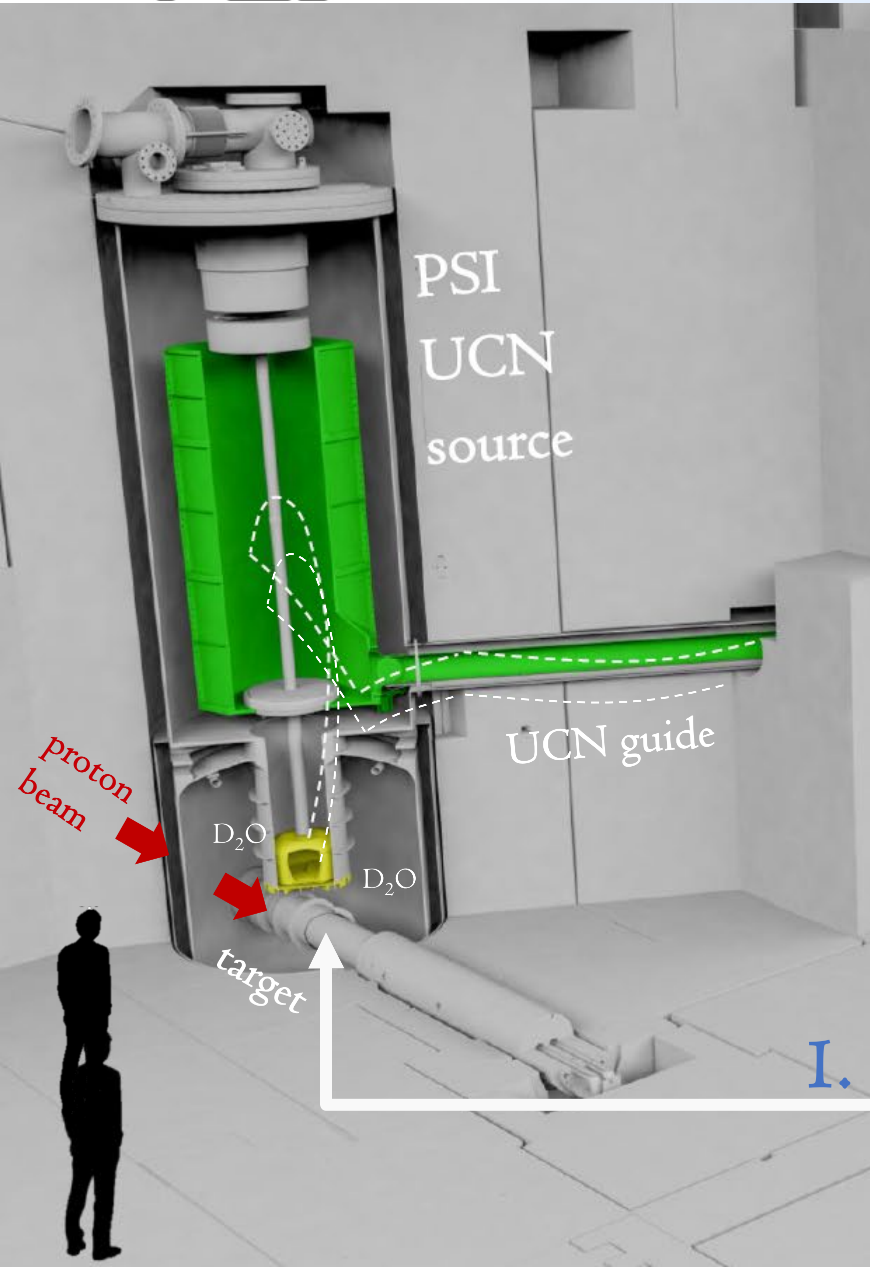
D2

D2O

spallation @ accelerator
p → Pb

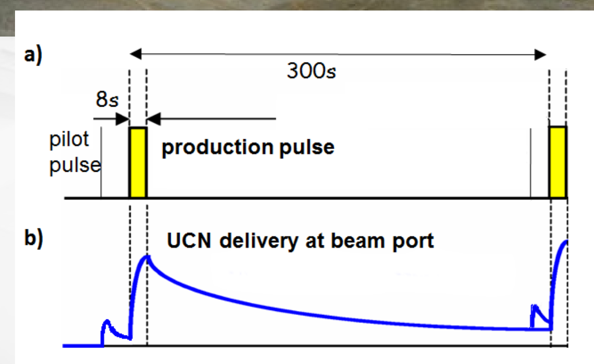
High intensity proton accelerator HIPA



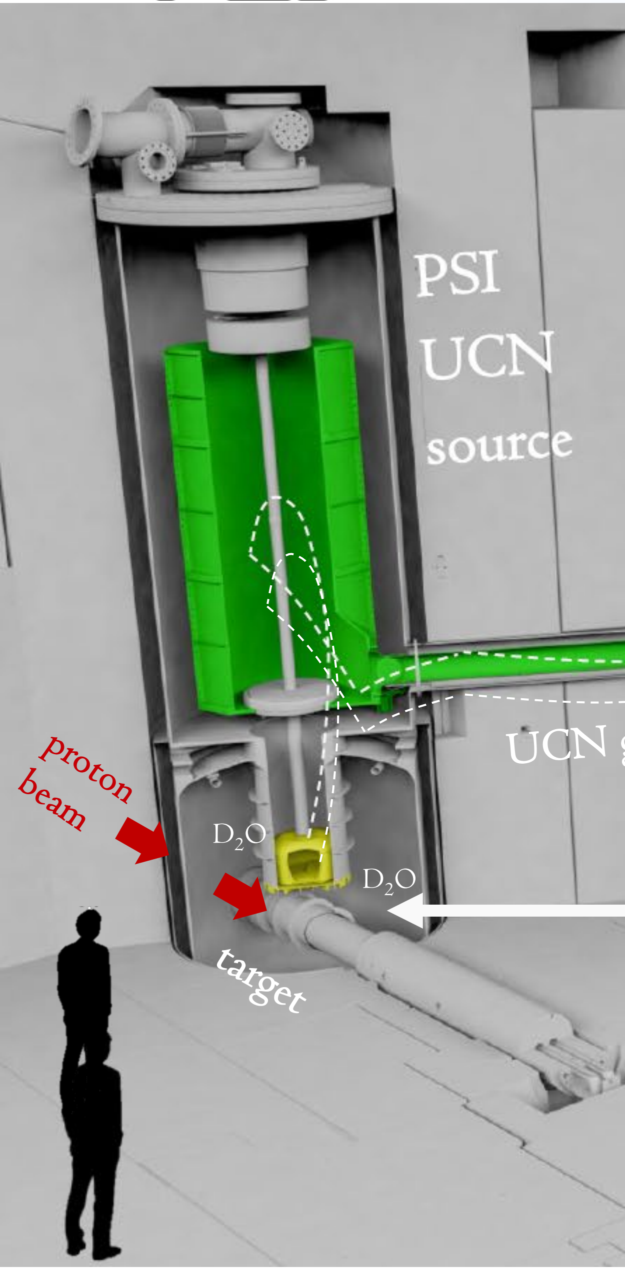


756
Zr/Pb
Canneloni

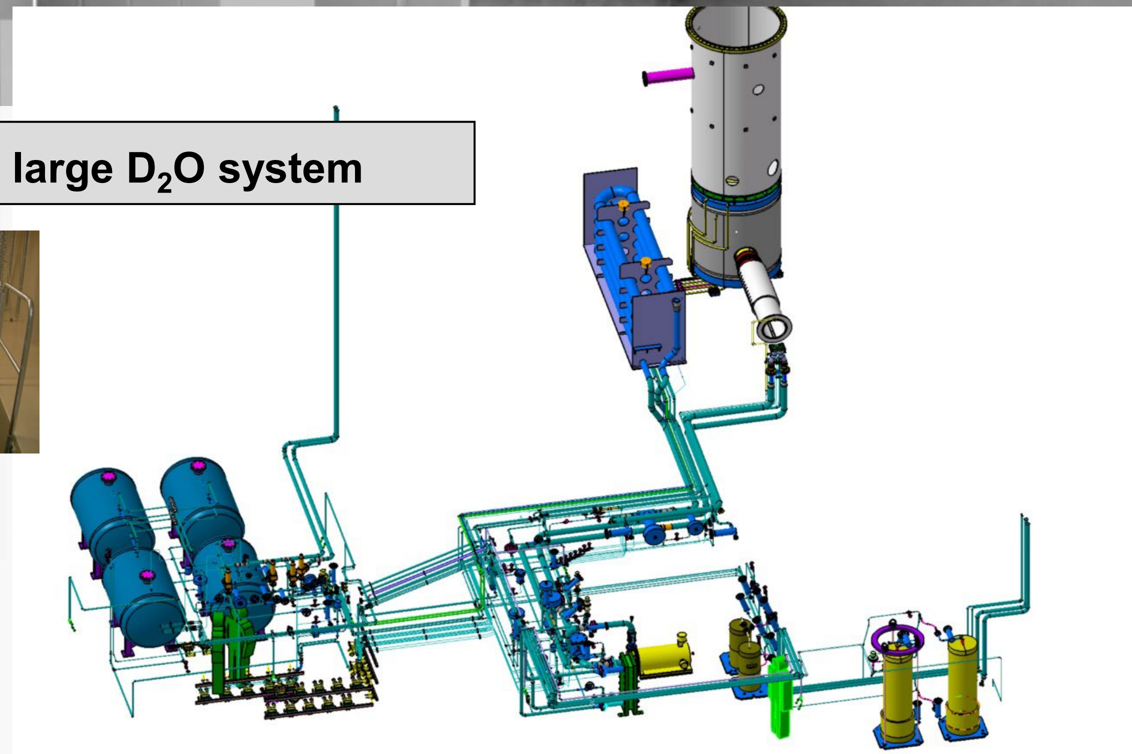
300s period



I. HIPA beam on Pb spallation target (up to 8s)
produces ~8 free neutrons per proton



large D_2O system



2. Moderation in heavy water thermalizes neutrons at room temperature

+ target cooling

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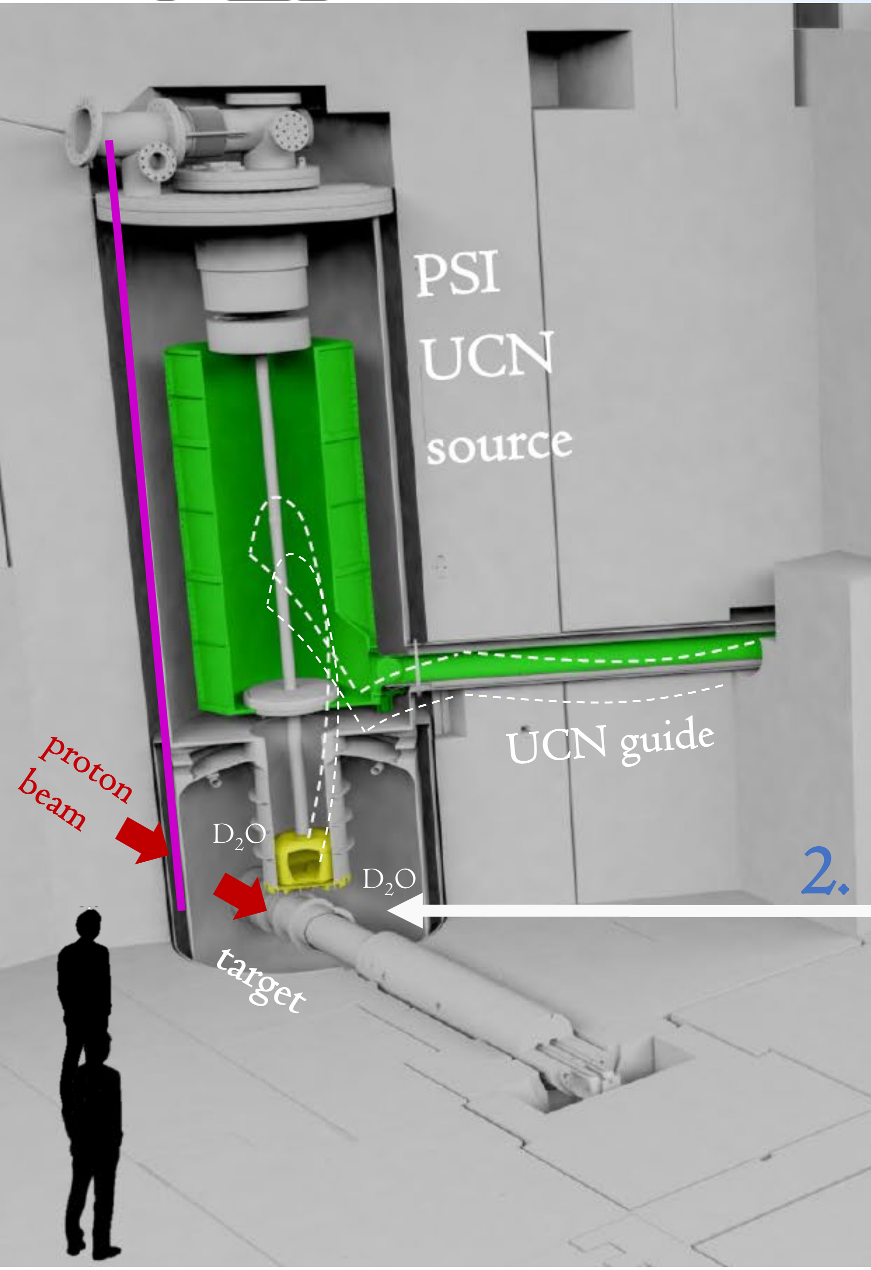

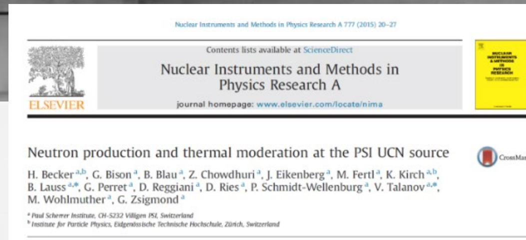
Nuclear Instruments and Methods in Physics Research A 777 (2015) 20–27

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

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

ELSEVIER

Neutron production and thermal moderation at the PSI UCN source

H. Becker[a,b], G. Bison[a], B. Blau[a], Z. Chowdhuri[a], J. Eikenberg[a], M. Fertl[a], K. Kirch[a,b], B. Lauss[a,*], G. Perret[a], D. Reggiani[a], D. Ries[a], P. Schmidt-Wellenburg[a], V. Talanov[a,*], M. Wohlmuther[a], G. Zsigmond[a]

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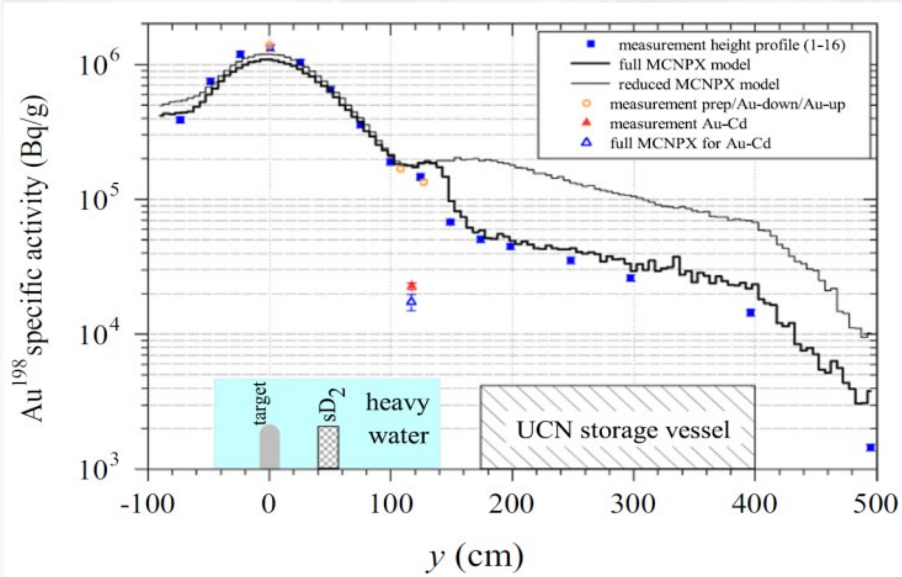
Thermal flux
MCNP-X + gold foil



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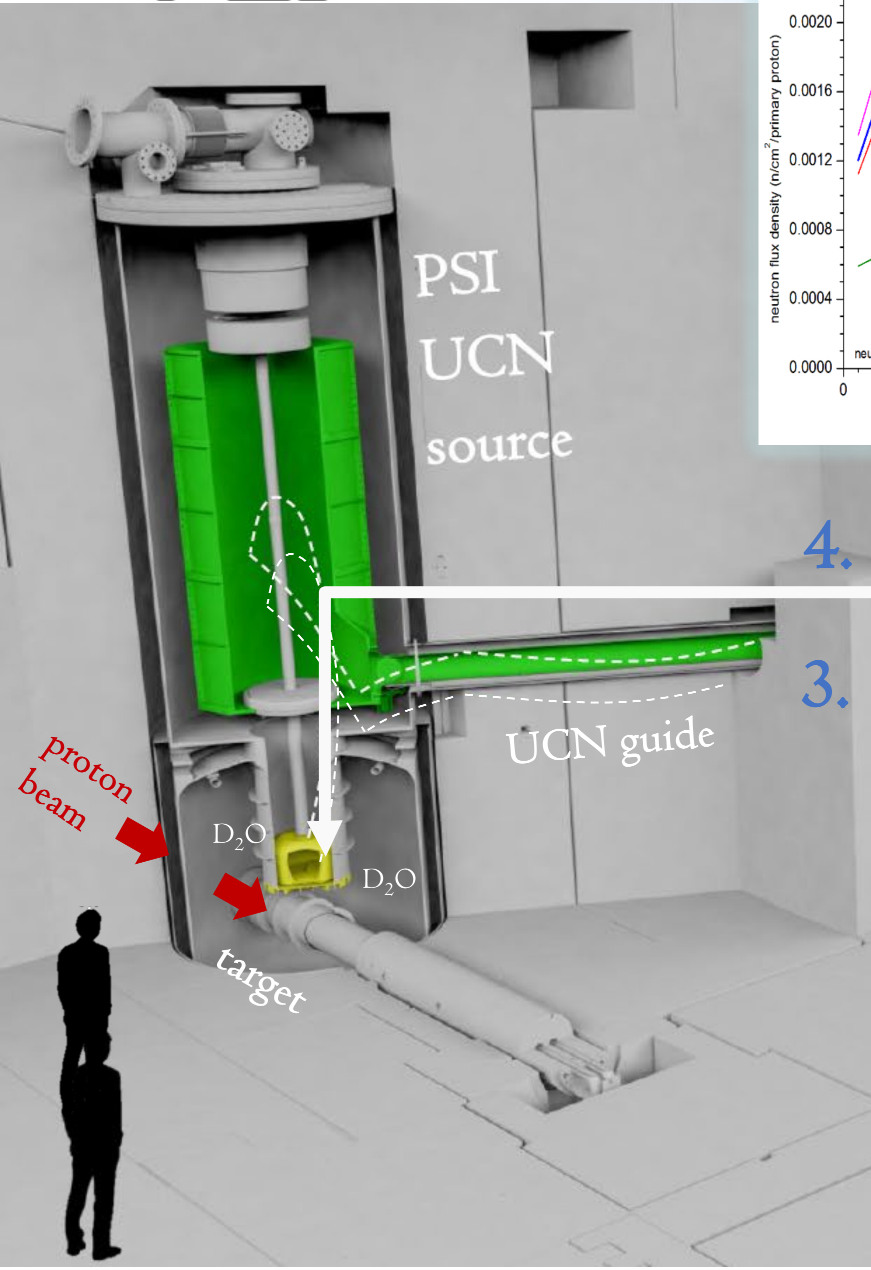
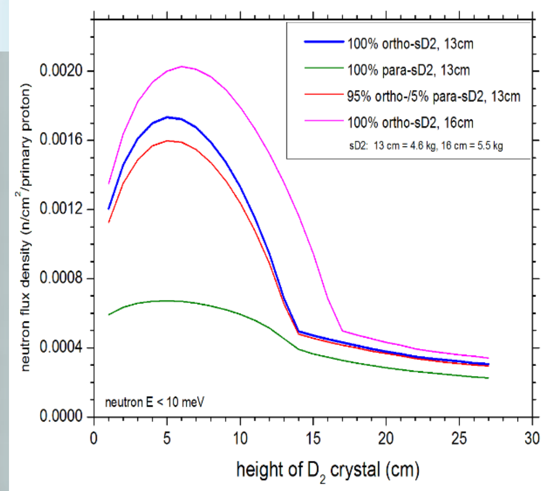




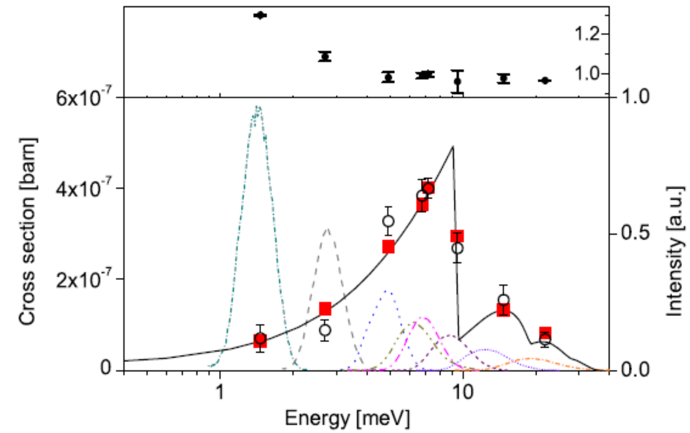
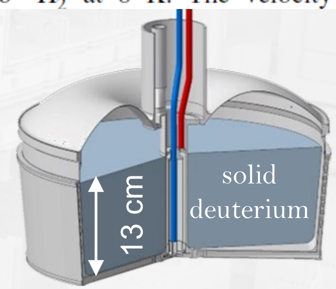

PRL **99,** 262502 (2007) PHYSICAL REV

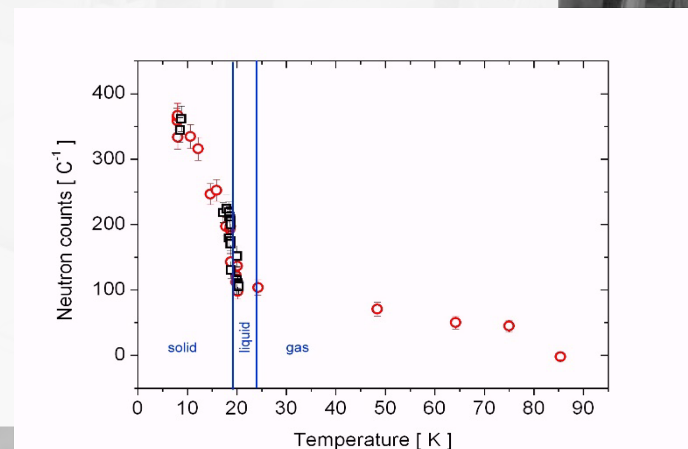
FIG. 4 (color online). Scaled measured (open circles) and calculated UCN production cross sections per molecule (multi-phonon Debye model: continuous black line and red squares; see text) for solid ortho $^2H_2$ at 8 K. The velocity-selected CN

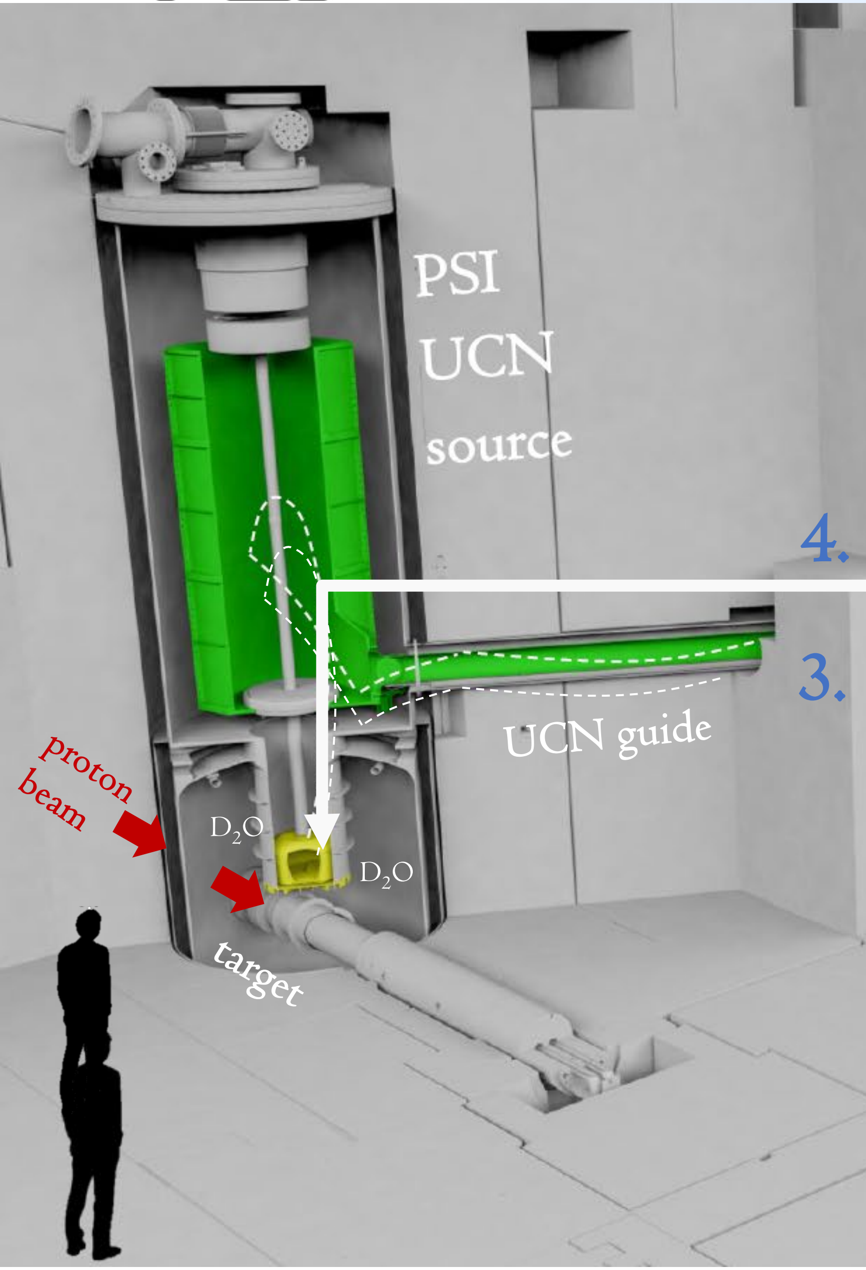
4. **Conversion to UCN** by phonon excitation in solid deuterium



3. **Cold neutron flux** from moderation in solid deuterium at 5 Kelvin

5K as operation point of source





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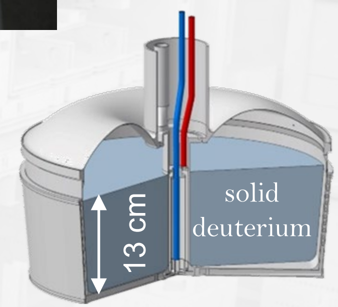

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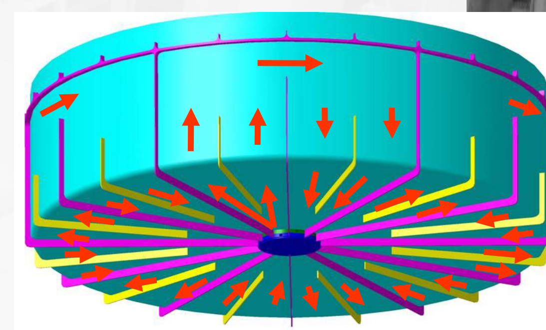
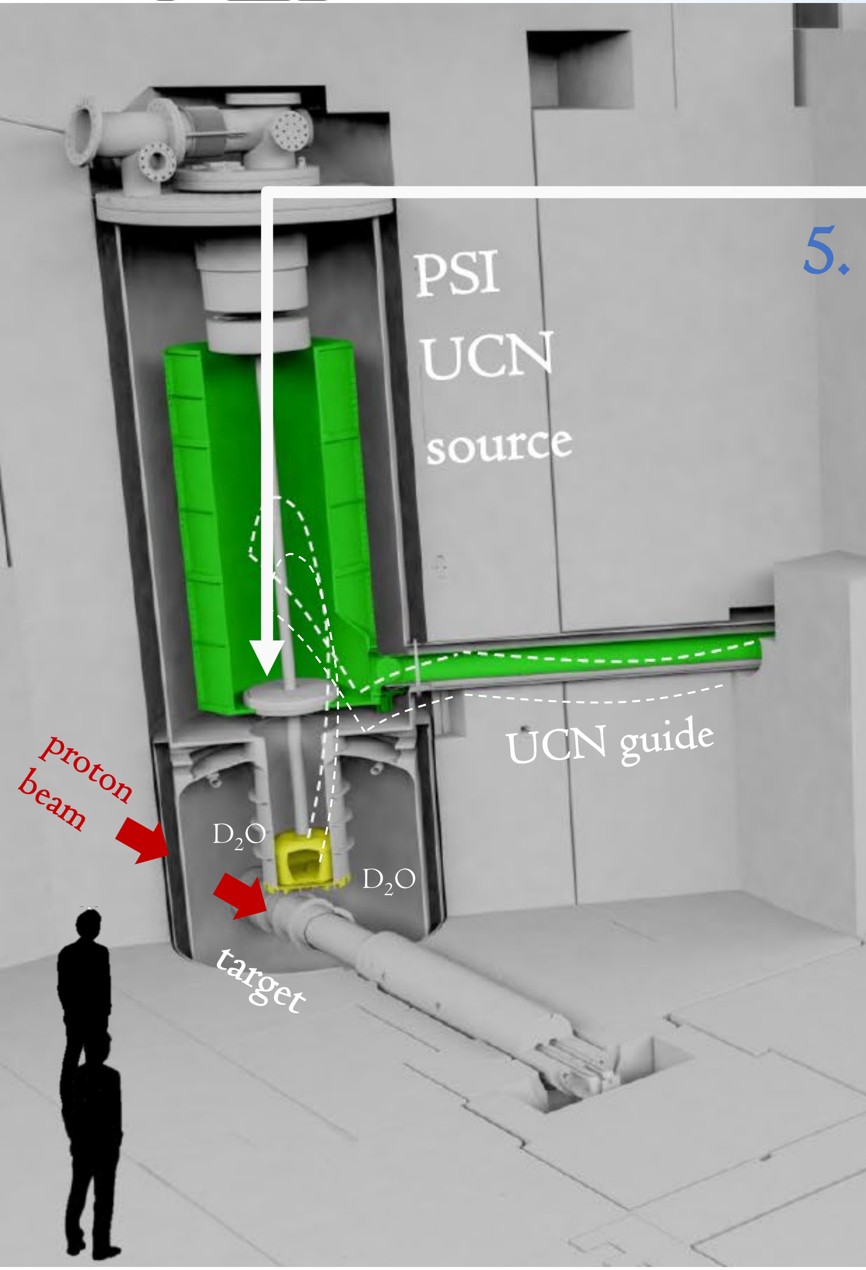
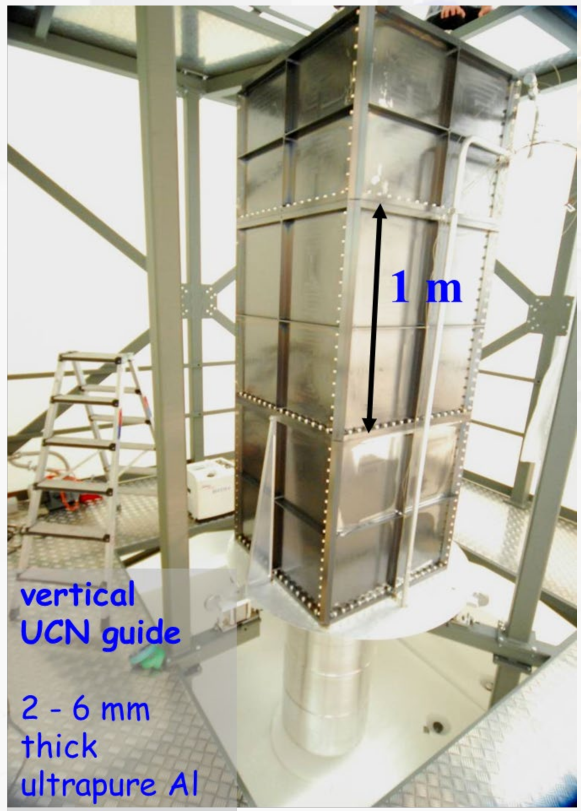
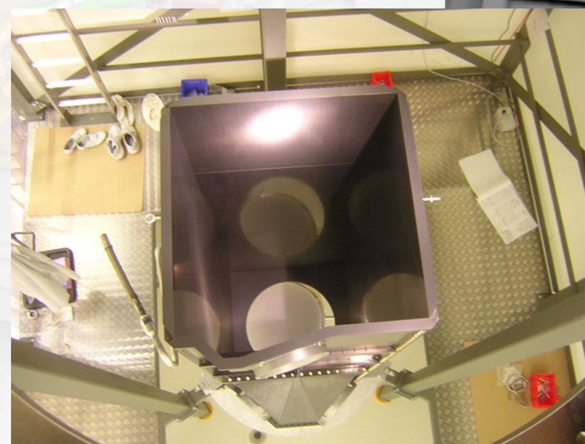
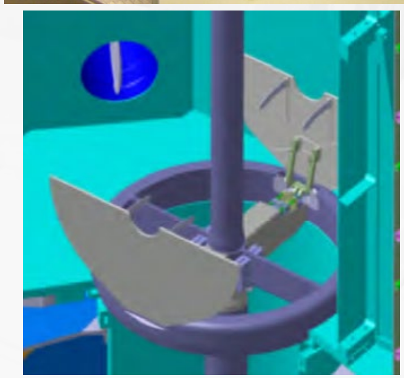


5. Two storage flaps close to confine the UCN in the storage volume

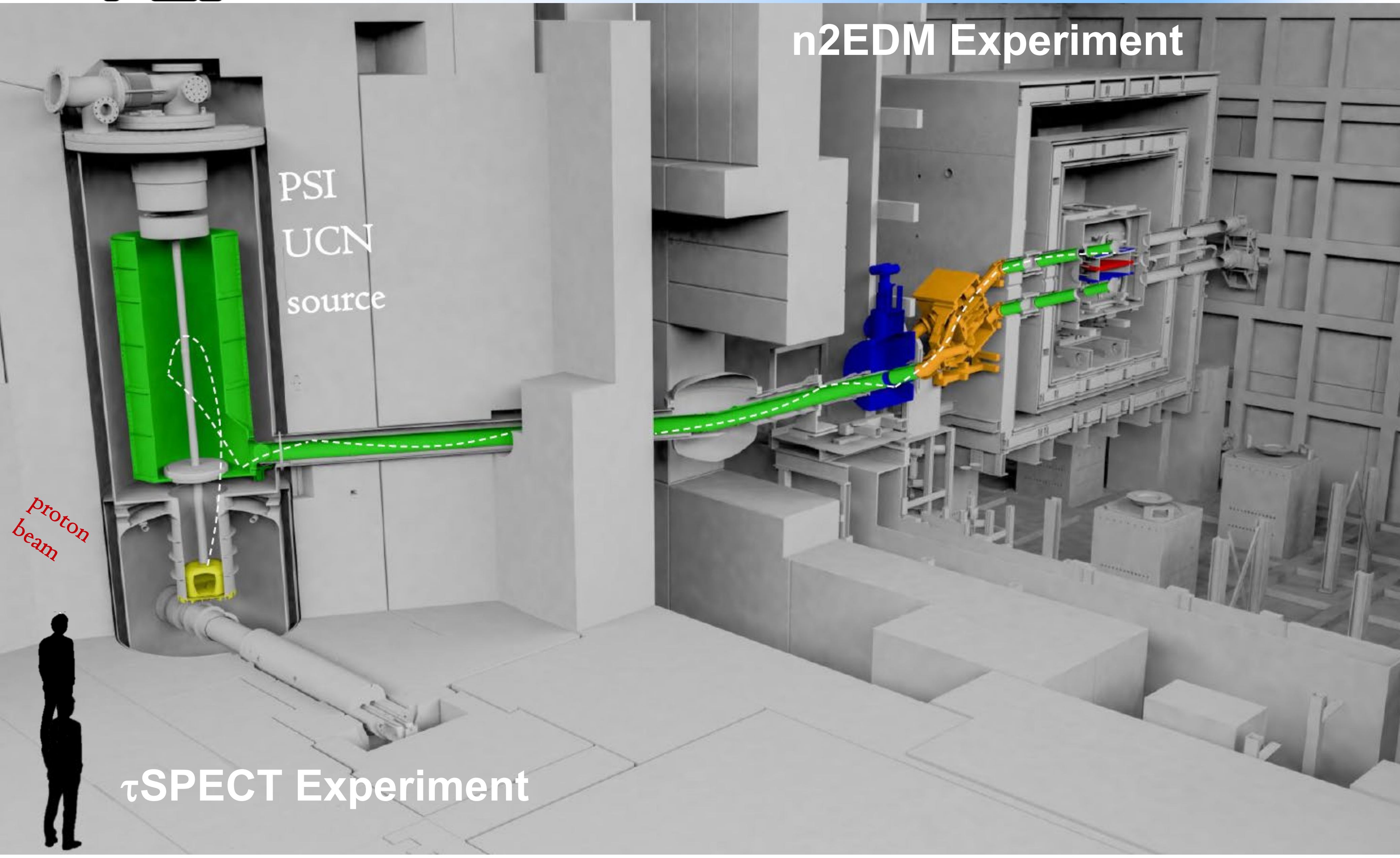








UCN delivery to Experiments



UCN Tank

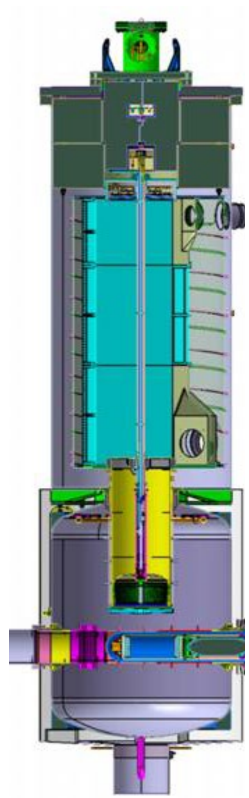
delivery of tank:
Sept. 04, 2008

June
2009

December
2009

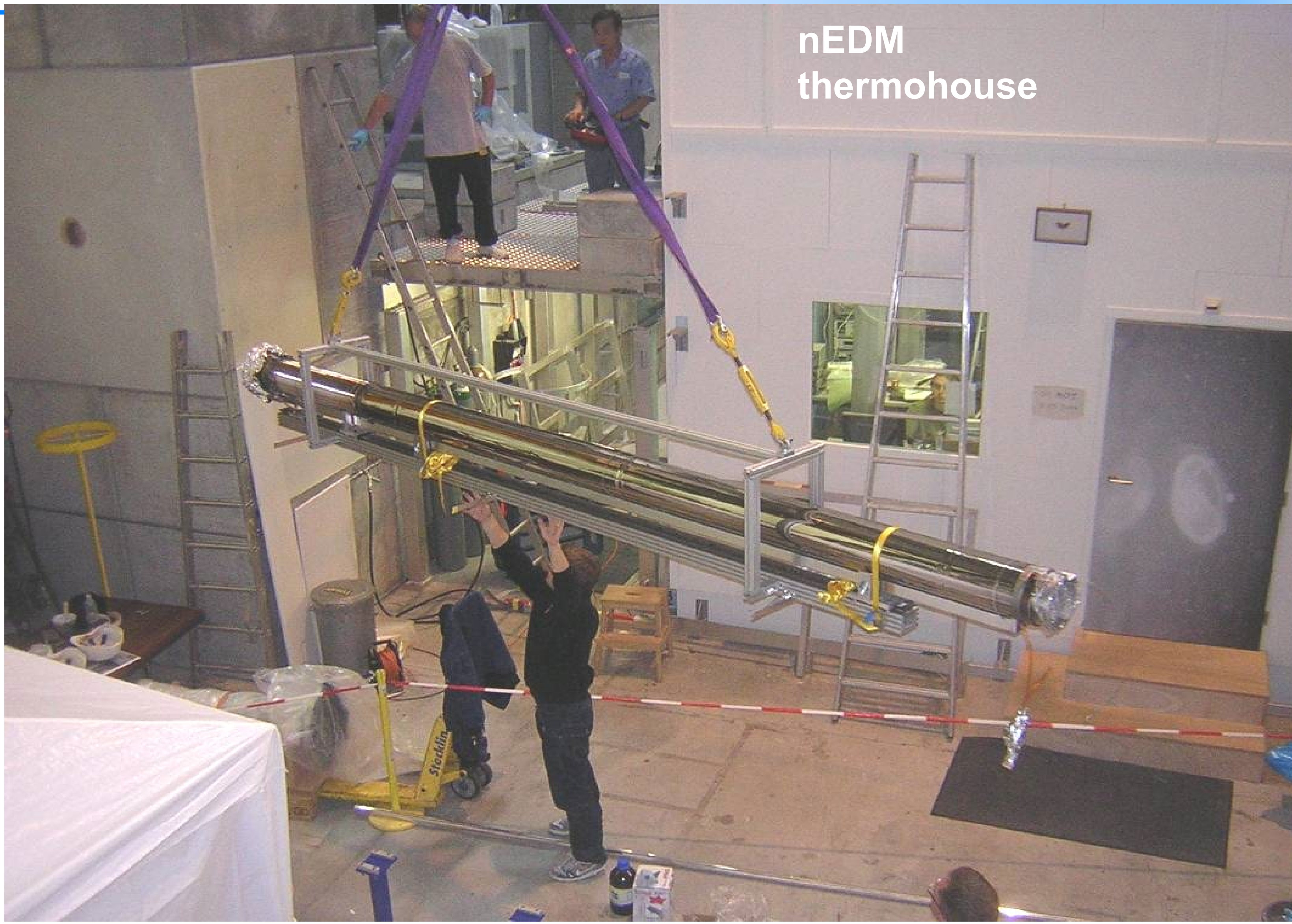
Installation of the storage volume unit and the deuterium unit

fall 2010



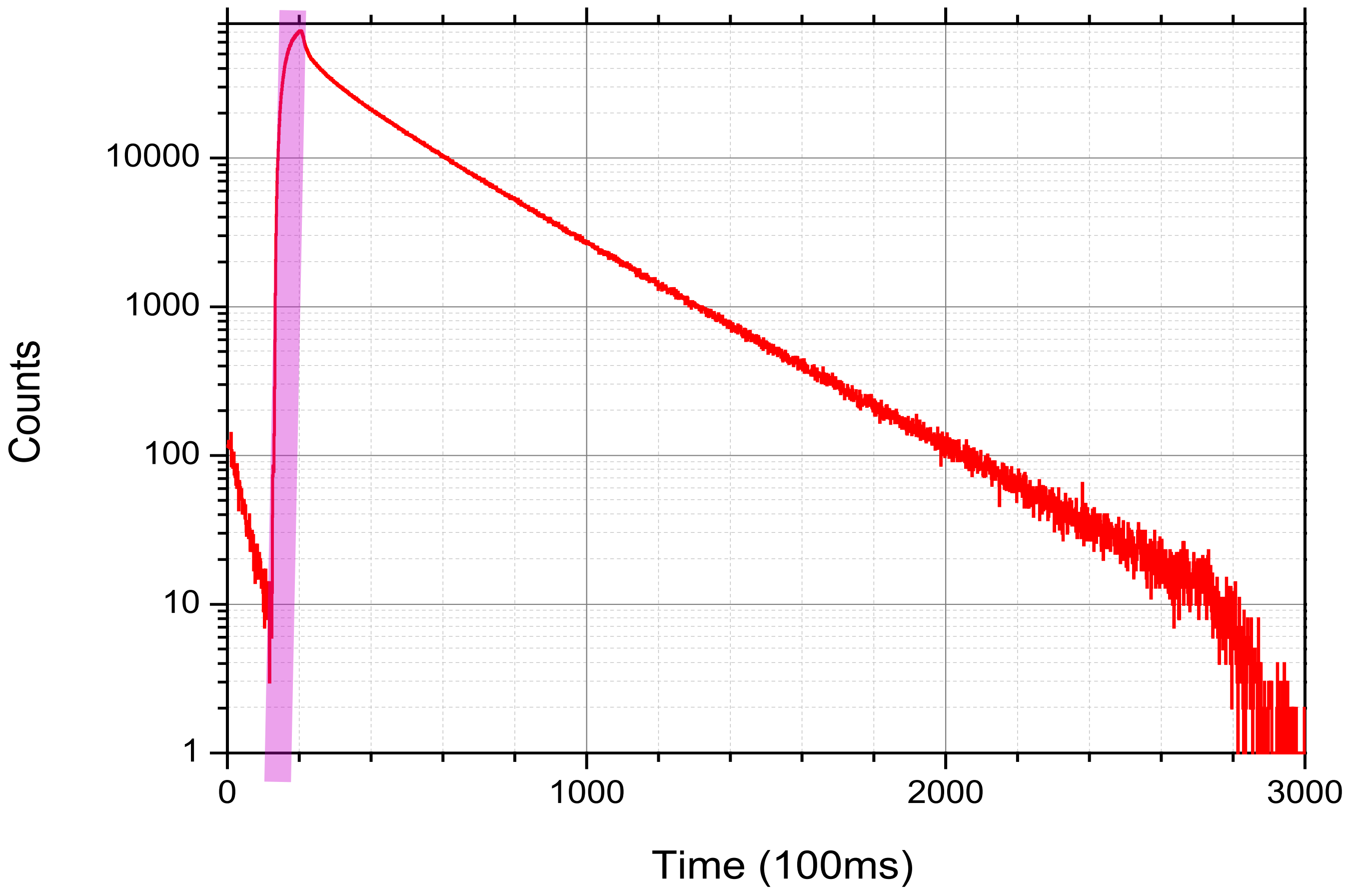
← ±15mm

Installation of longest UCN guide towards nEDM

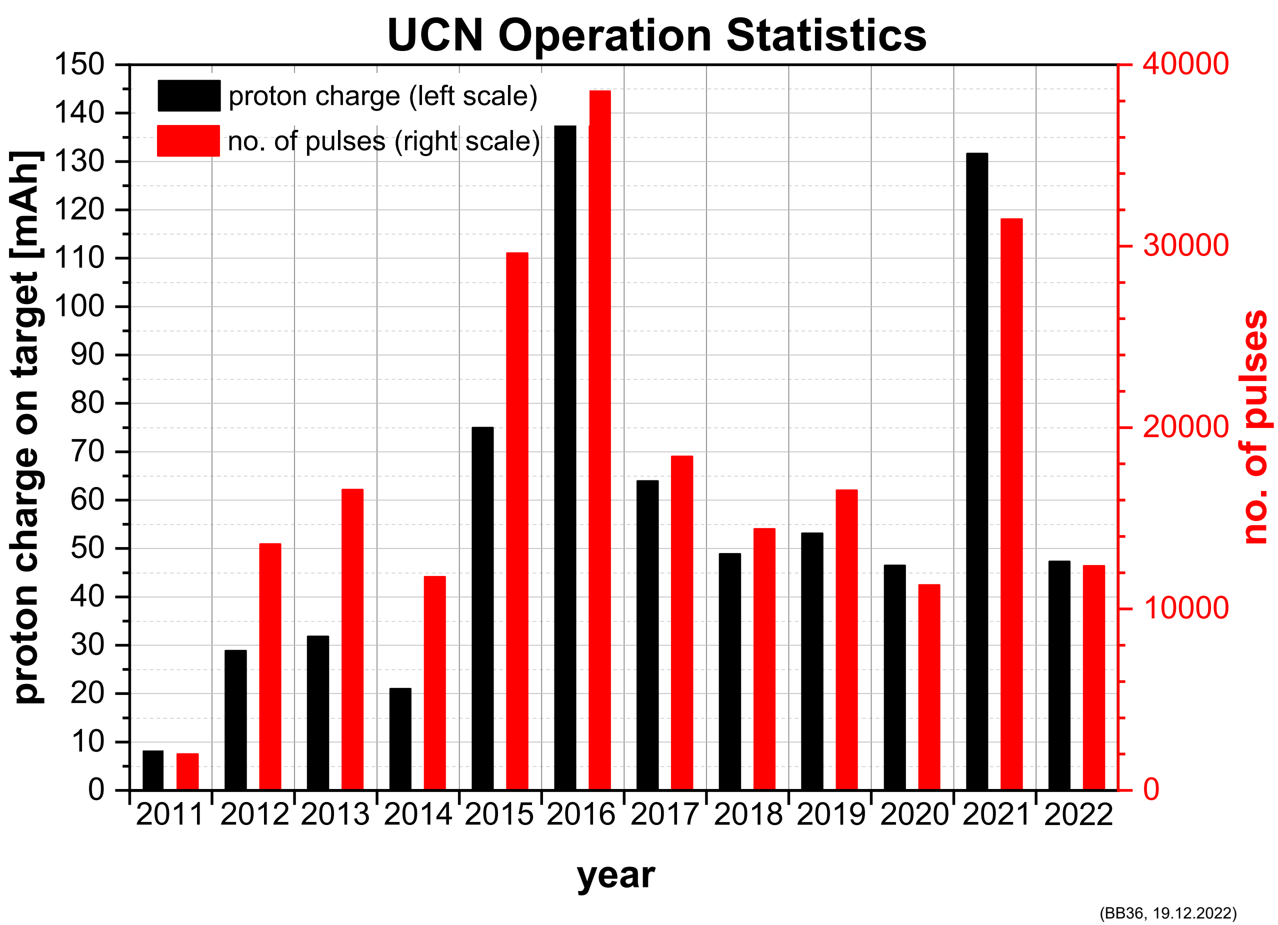


UCN delivery

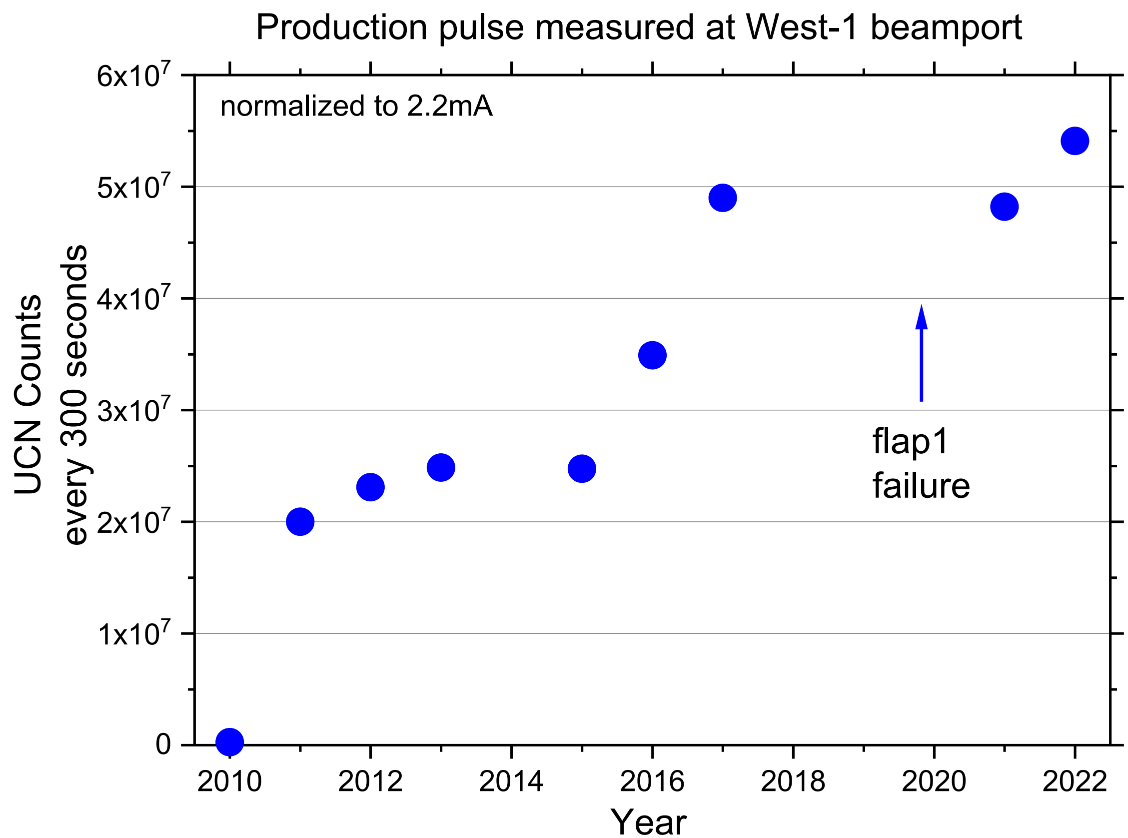
up to 50 Mio UCN every 6 min at one beamport



UCN operation



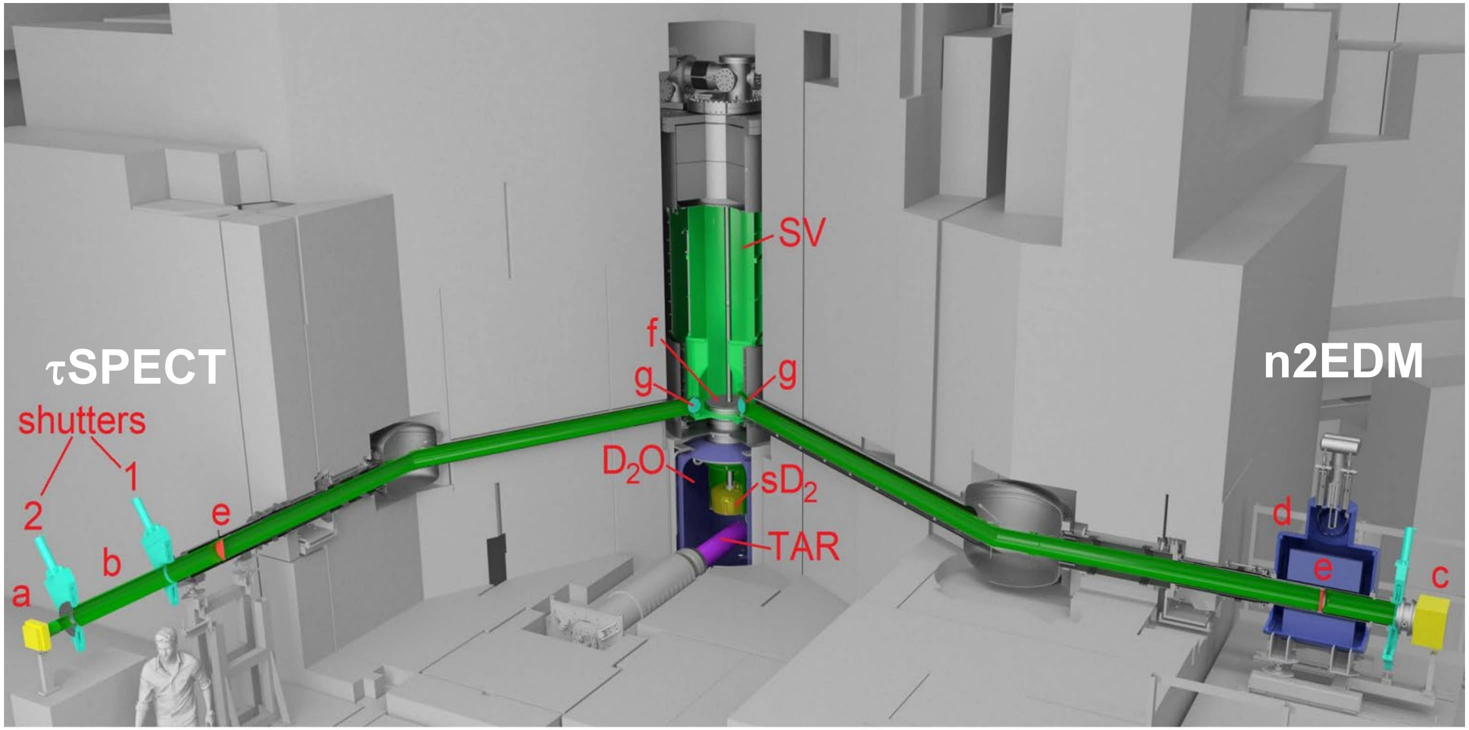
UCN intensity improvement



Operation in 2022 with
largest D2 mass = 5.677 kg

achieving high UCN intensities needs various optimizations ⟶

minimize mechanical losses
UCN transport efficiency



- UCN guides made from glass tubes or highly polished stainless steel tubes
- coated with Nickel-Molybdenum
- long effort to fully understand the complex system

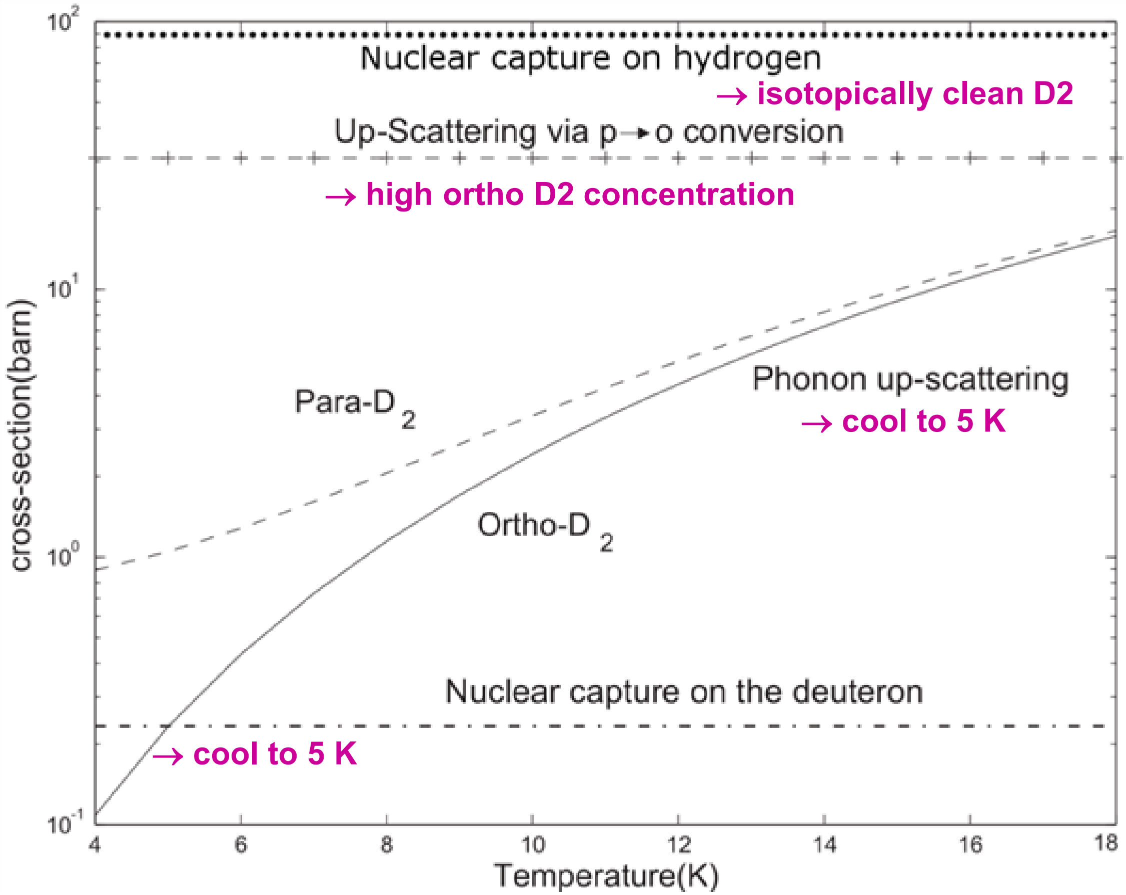
UCN transmission spectra calibrated by

- "ping-pong" transmission measurements
- storage time and time of arrival spectra
- UCN density measurements in storage bottles at different heights
- time of flight spectroscopy

G. Bison et. al., Eur. Phys. J. A 56, 33 (2020)
G. Bison et. al., Eur. Phys. J. A. 58 ,103 (2022)
G. Bison et. al., EPJ A 59, 215 (2023)

minimize UCN losses in D2 $\tau_{UCN} = 1 / \sum(\sigma v)$

loss cross-sections

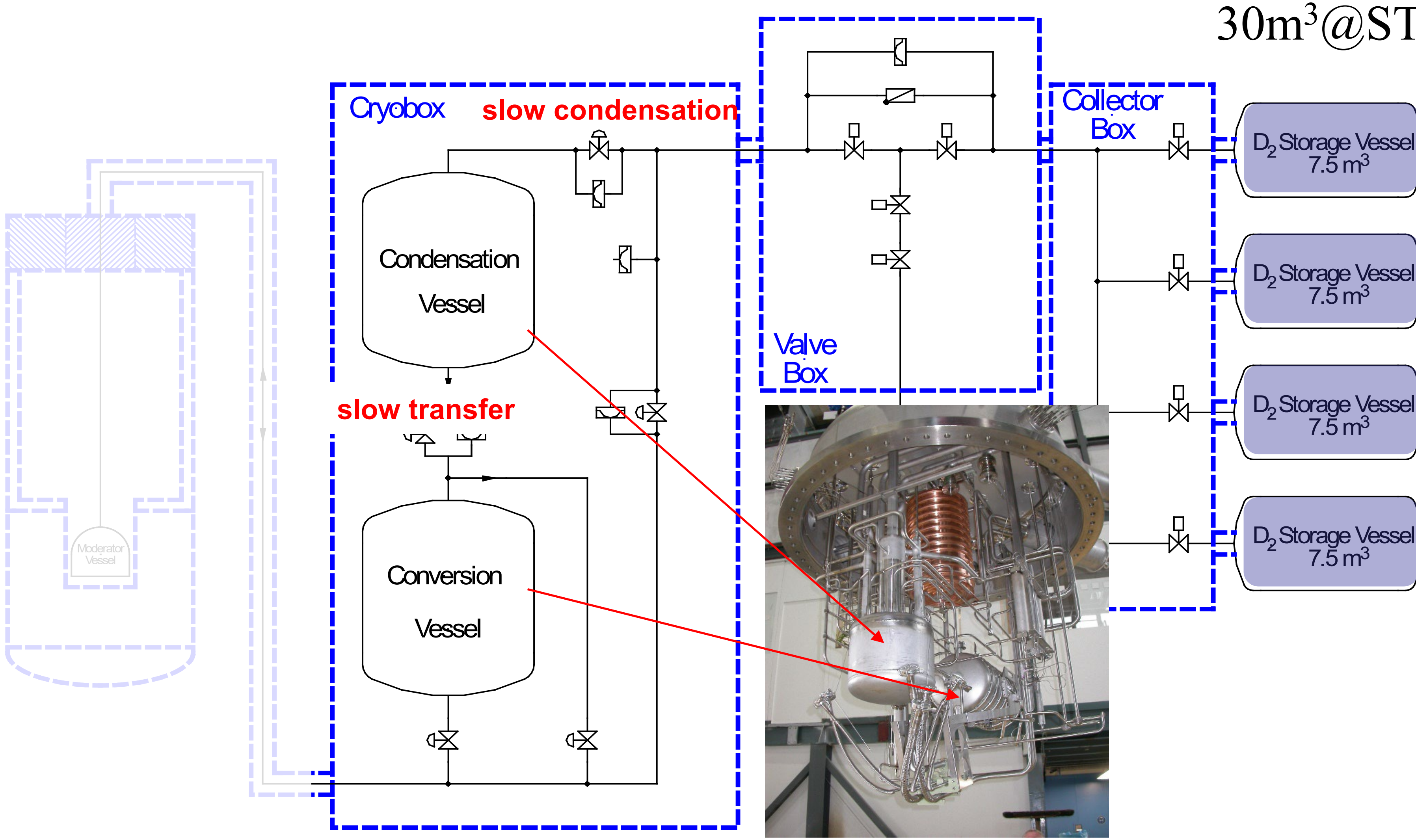


Modified plot from
C.-Y.Liu, A. Young, S.K. Lamoreaux, Phys. Rev. B 62 (2000) R3581

Preparation of the deuterium

He-refrigerator cooling power: 370W @4.2K and 2500W @ 80K

$30m^3$@STP



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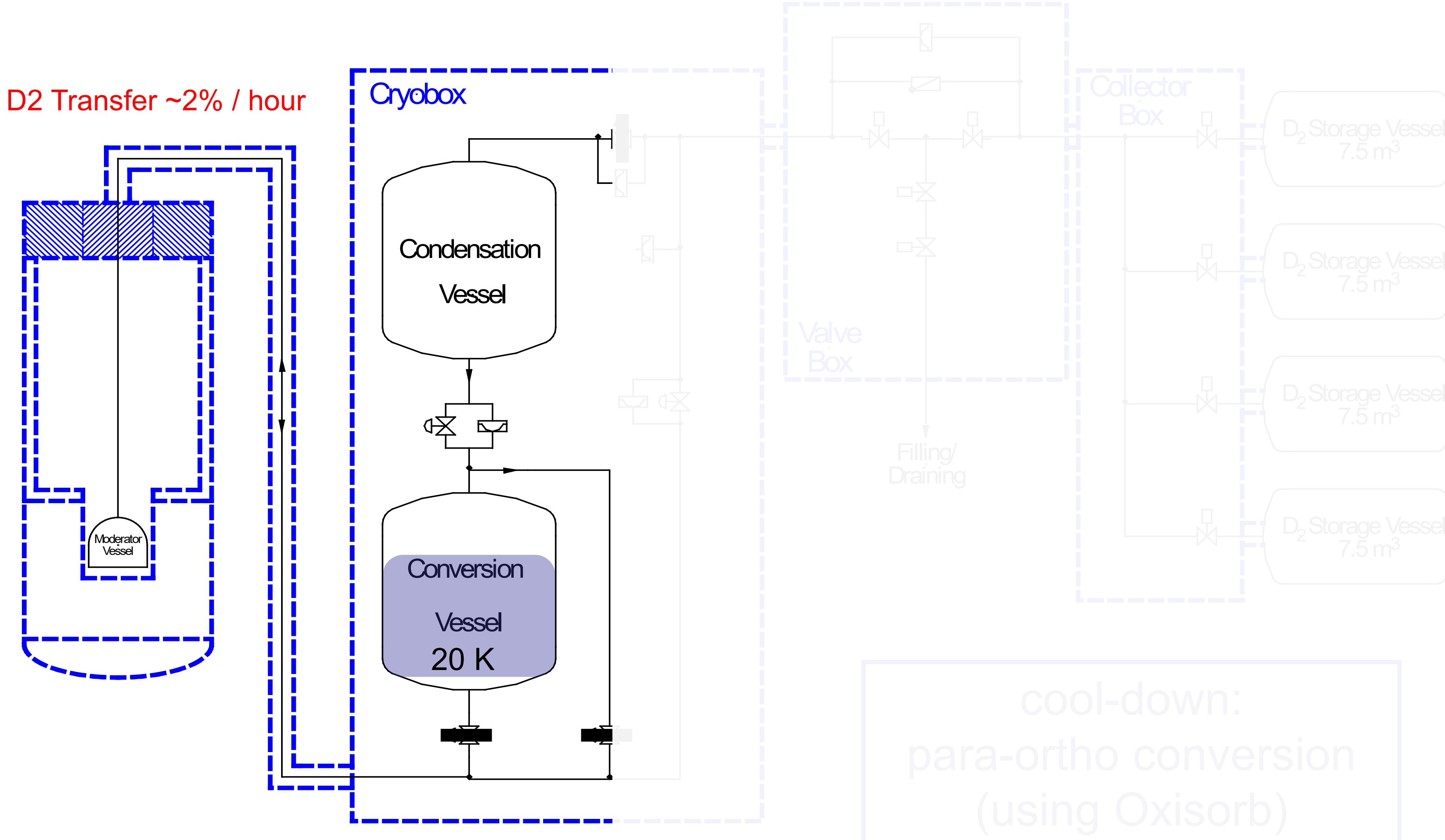
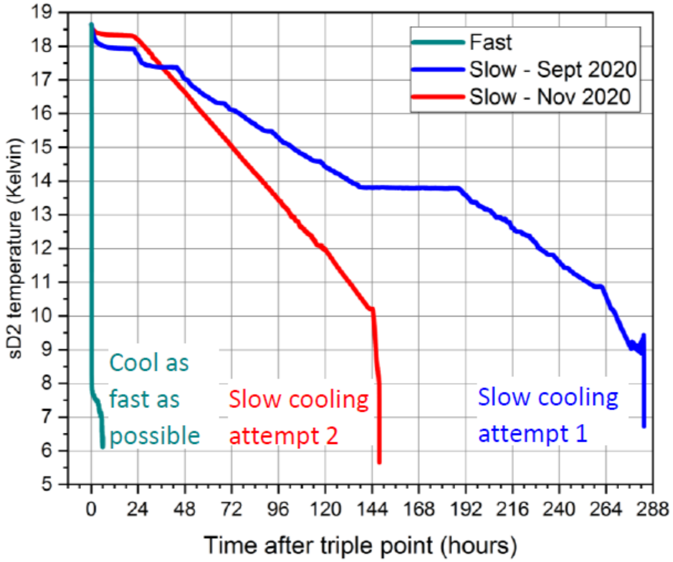
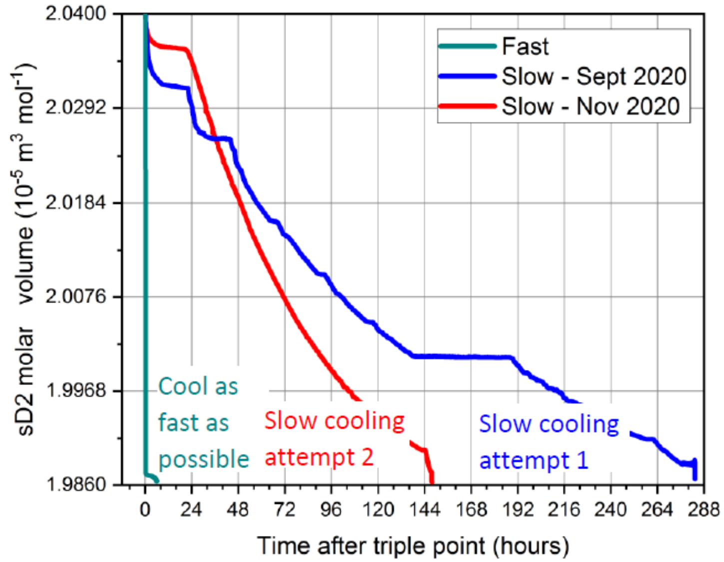


Slow freezing procedure

sD2 vapor pressure ↔ sD2 temperature ↔ sD2 molar volume

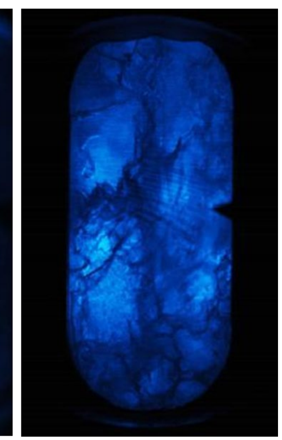
PhD I..Rienacker





slow crystal

fast growing



Photos: PhD thesis M.Kasprzak

Solid deuterium surface degradation

EPJ A Highlight - Solid deuterium surface degradation at ultracold neutron sources

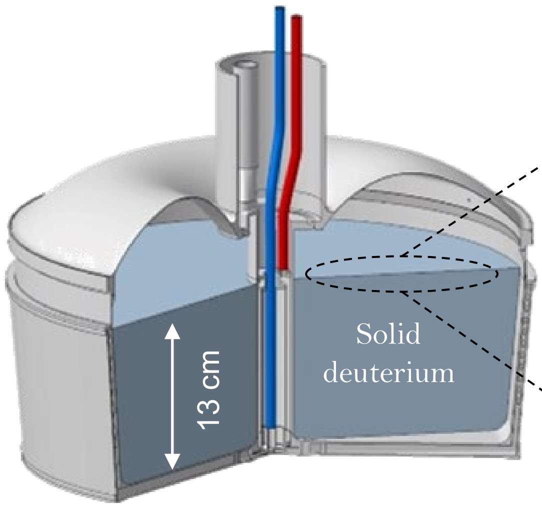
Published on 11 September 2018

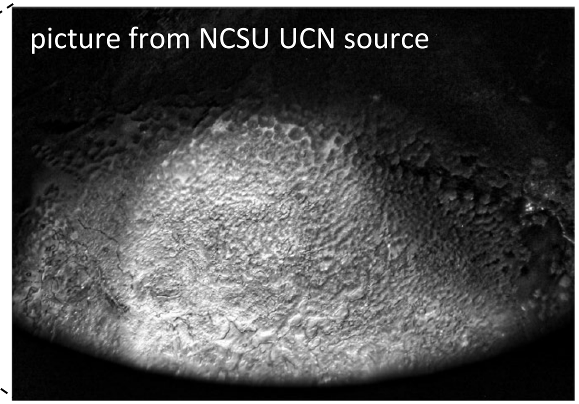
Sublimation:
Heat deposition during proton beam pulse causes sublimation of D2 vapor

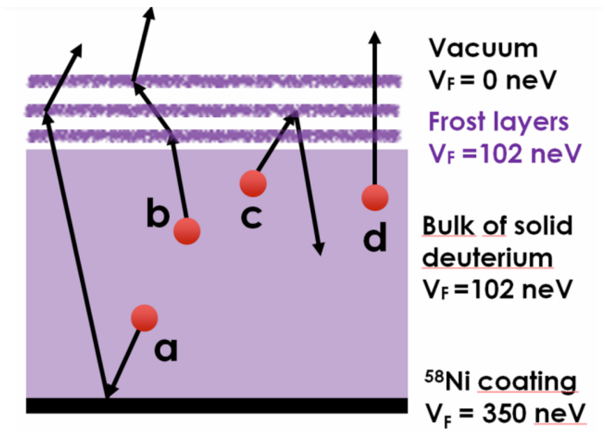
Frost deposition:
After the proton beam pulse the D2 vapor is deposited on the cold sD2 surface and forms an opaque frost layer

Albedo reflection:
Frost layer causes Albedo reflection of UCN back into the sD2 bulk where they are lost due to upscattering and absorption

Eur. Phys. J. A (2018) 54: 148



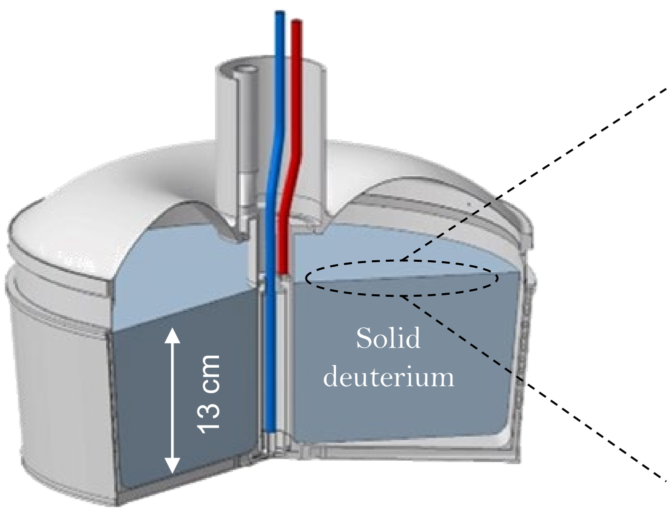


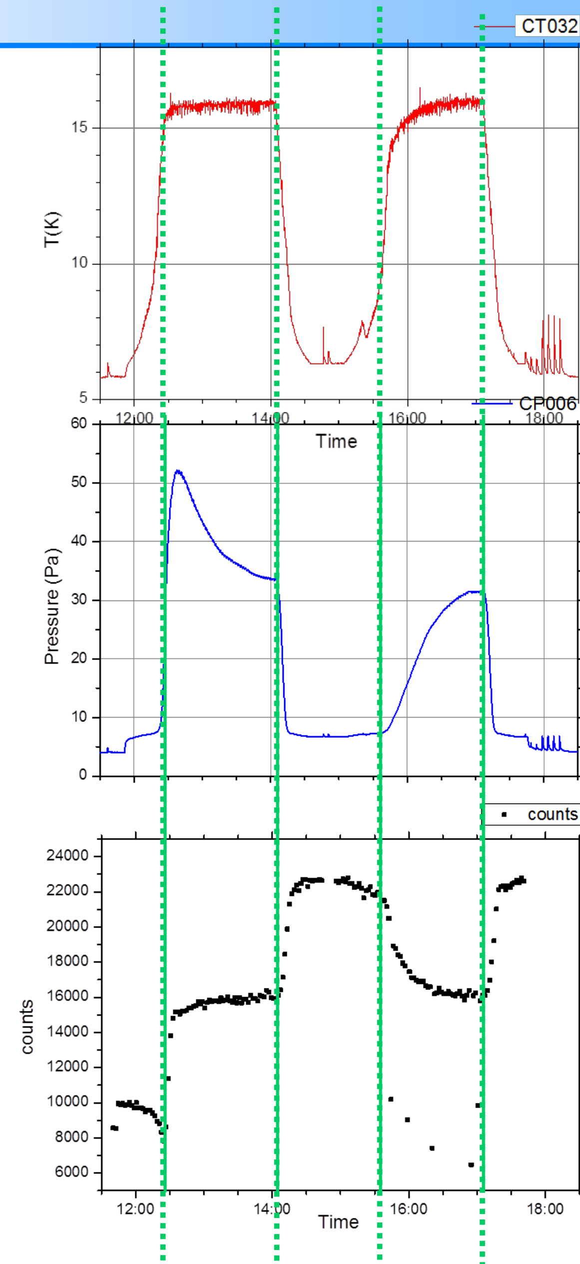


conditioning procedure - 'surface heating' - regains full UCN output

Solid deuterium surface degradation

Sublimation:
Heat deposition during
proton beam pulse
causes sublimation
of D2 vapor

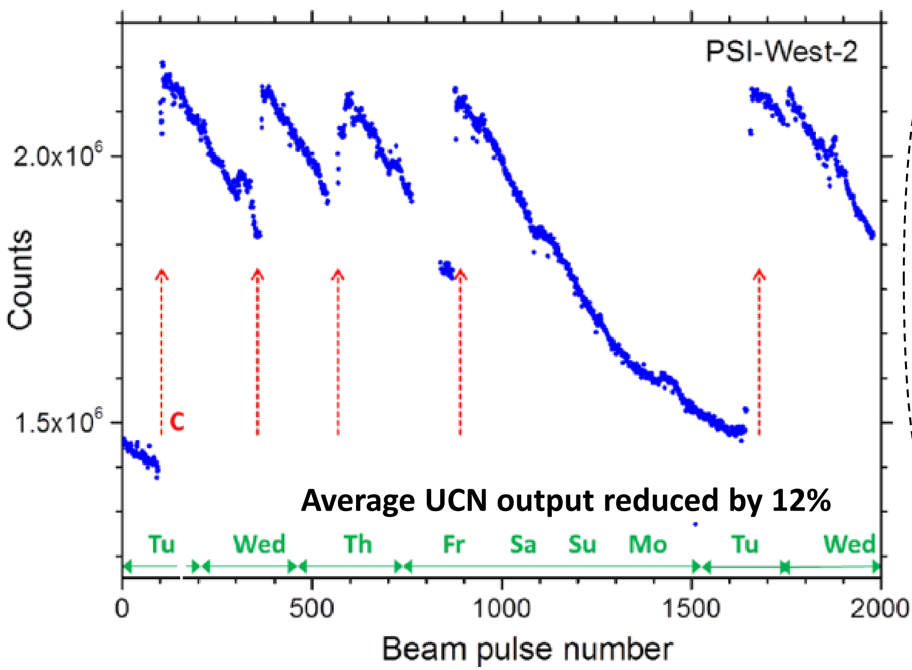




conditioning procedure - 'surface heati

sD_2 conditioning procedure

A regular conditioning procedure anneals the sD2 surface and recovers UCN output



Conditioning:

- Stop proton beam pulses
- Decrease cooling power
- Turn on heating elements on moderator vessel for approx. 2 hours

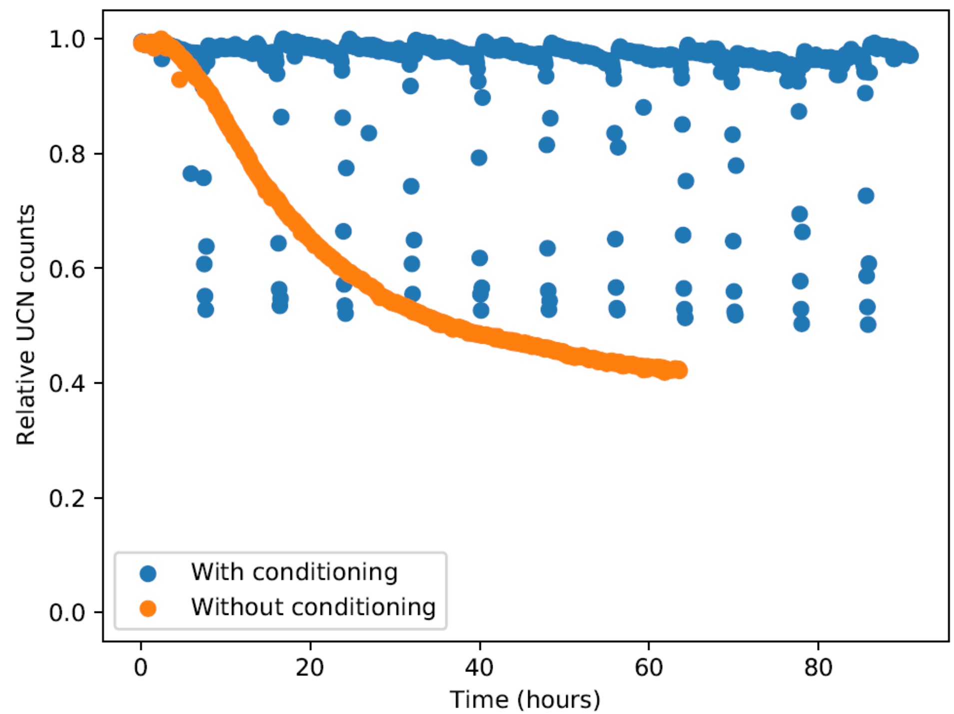
2 hours / 24 hours = 8% of the time no UCN production

automated procedure with beam

The new conditioning procedure recovers the UCN output just as the standard conditioning for all cases investigated until now

Estimated gain on average UCN output: ≈ 20%

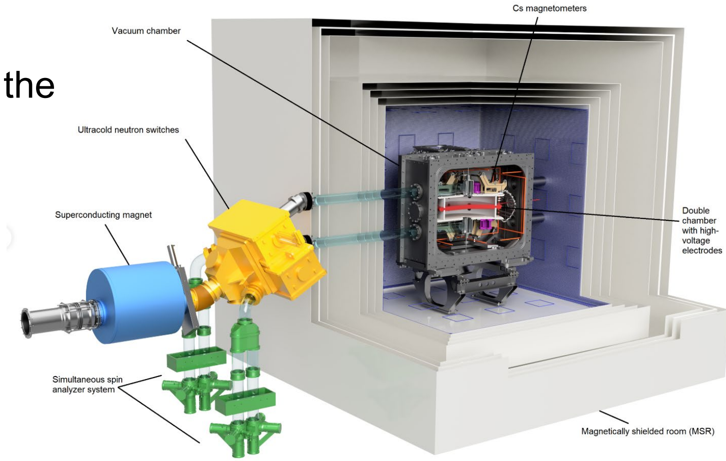
automated conditioning

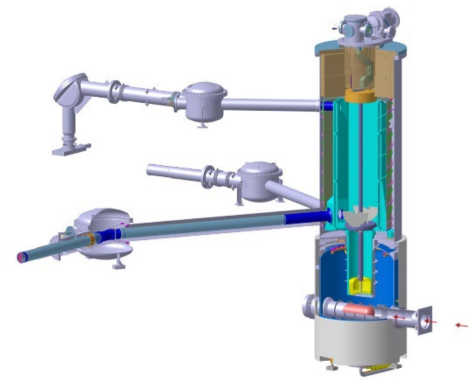


All efforts to provide high UCN intensity to fundamental physics experiments

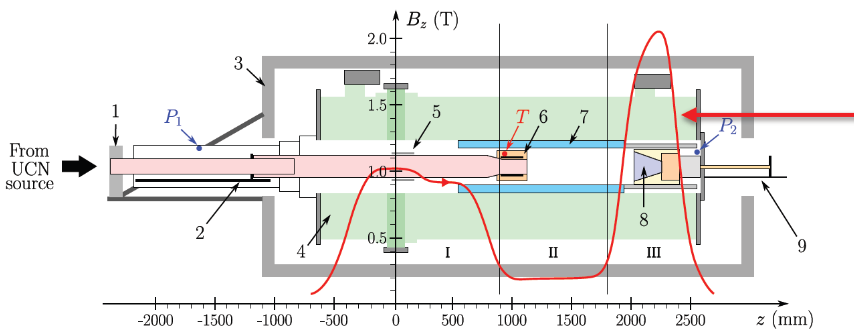
Search for the neutron electric dipole moment with the n2EDM apparatus by the nEDM collaboration
- talk by Anthony Lejuez

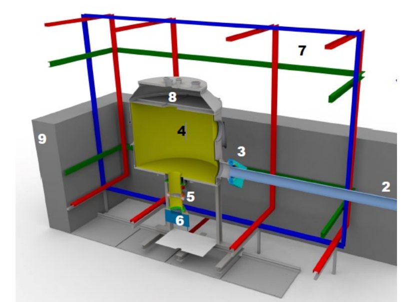
n2EDM





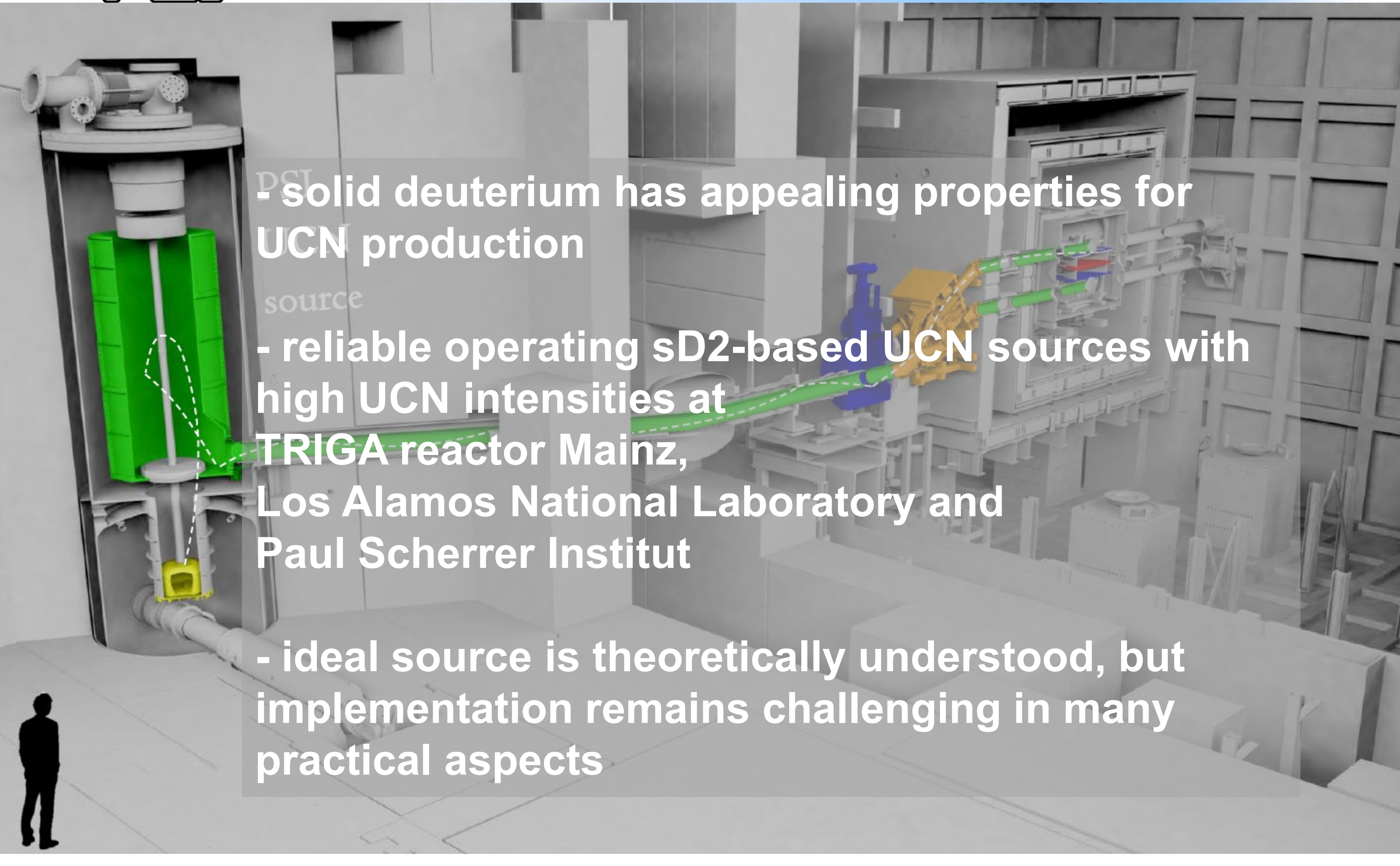
Precision measurement of the lifetime of the free neutron - tauSPECT collaboration
- talk by Dieter Ries





Search for neutron to mirror-neutron oscillations, nn' collaboration
Symmetry **2022**, 14, 503. https://doi.org/10.3390/sym14030503

Summary



- solid deuterium has appealing properties for UCN production

- reliable operating sD2-based UCN sources with high UCN intensities at
TRIGA reactor Mainz,
Los Alamos National Laboratory and
Paul Scherrer Institut

- ideal source is theoretically understood, but implementation remains challenging in many practical aspects

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Ultra Cold Neutron Source

thanks for your attention

thanks to all colleagues for transparencies and inputs