The solid-deuterium-moderator-based ultracold neutron source at PSI

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Paul Scherrer Institute

on behalf of the PSI UCN Team

Sep. 2019

What are ultracold neutrons - UCN

UCN < 300neV ~ 8m/s ~ 3 mK

$$\lambda = \frac{h}{m \cdot v}$$

> 50 nm !

$$E_{\mathrm{kin}} = \frac{mv^2}{2} = \frac{3}{2}kT$$

e.g. air molecules at 20 °C: ~400 m/s

thermal (25 meV)	2200 m/s	300 K	0.18 nm
cold (5 meV)	1000 m/s	60 K	0.4 nm
UCN (< 260 neV)	< 7 m/s	0.003 K	> 50 nm

hence the name

Neutrons with E_{kin} < 300 neV reflect under any angly of incidence => cn be stored (E. Fermi, 1946)

UCN reflect under any angle of incidence → can be manipulated and stored

- storage properties are material dependent
e.g. Ni, Ni^{58}, Be, DLC, steel

V_F = 150 - 300 neV
(neutron optical potential)

magnetic

$V_m = -\mu B$

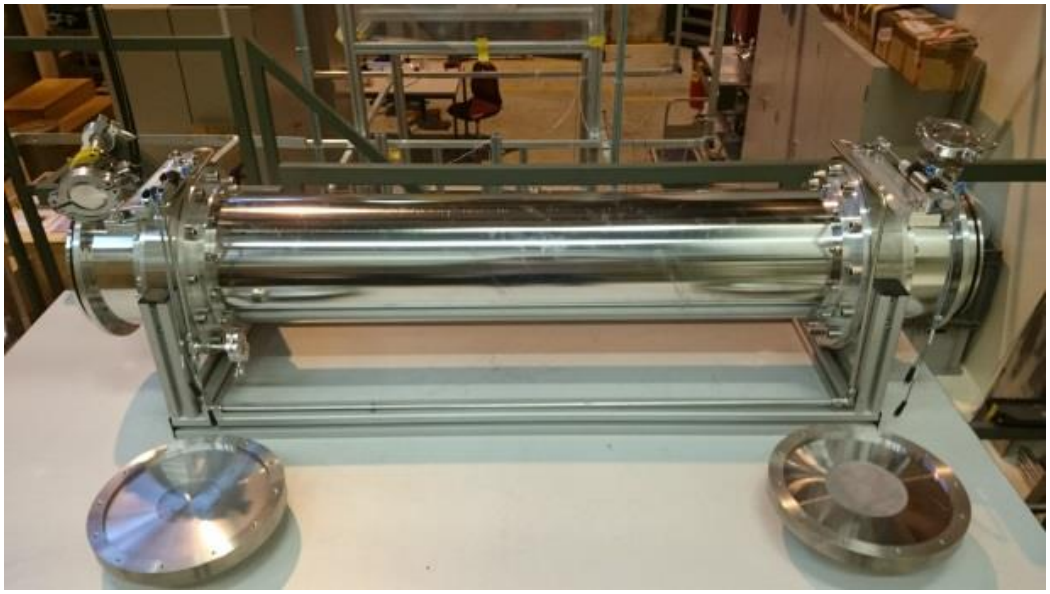
60 neV T^{-1}

gravitation

$V_g = m_n g h$

100 neV m^{-1}

Standard Storage Bottle



UCN reflect under any angle of incidence → can be stored

Comparison of ultracold neutron sources for fundamental physics measurements
G.Bison et al., Phys.Rev.C95 (2017) 045503

Suggestion of "standard" method and device for UCN density measurement and comparison:
G.Bison et al., Nucl.Instrum.Meth. A 830 (2016) 449

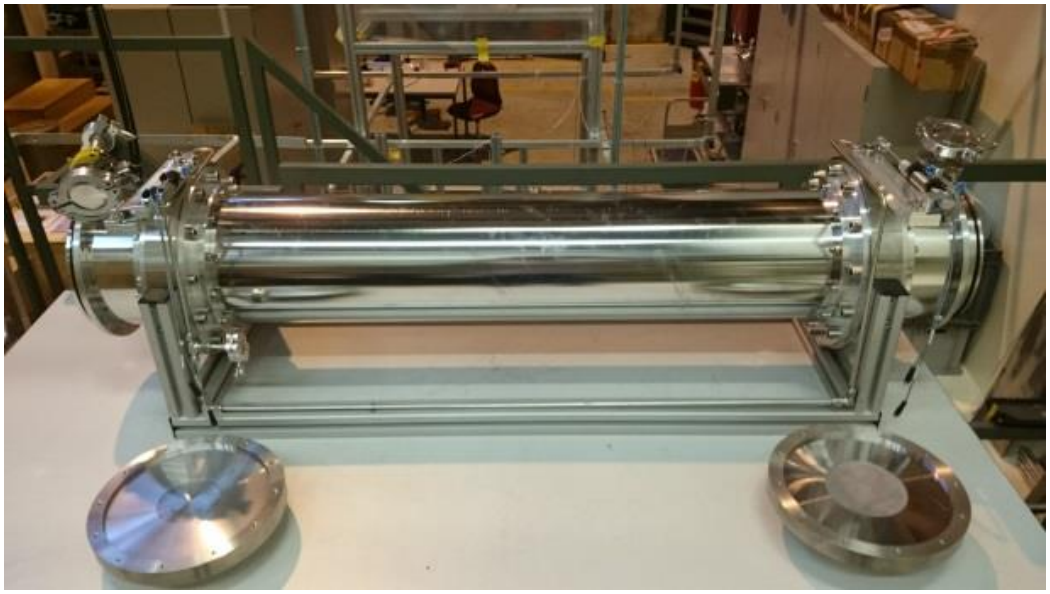
Standard storage bottle

Relevant parameter for UCN sources and storage experiments

UCN density

e.g. ~30 UCN/cm^3 in experiment at PSI

- fundamental physics experiments
e.g. search for a permanent elecdric dipole moment of the neutron



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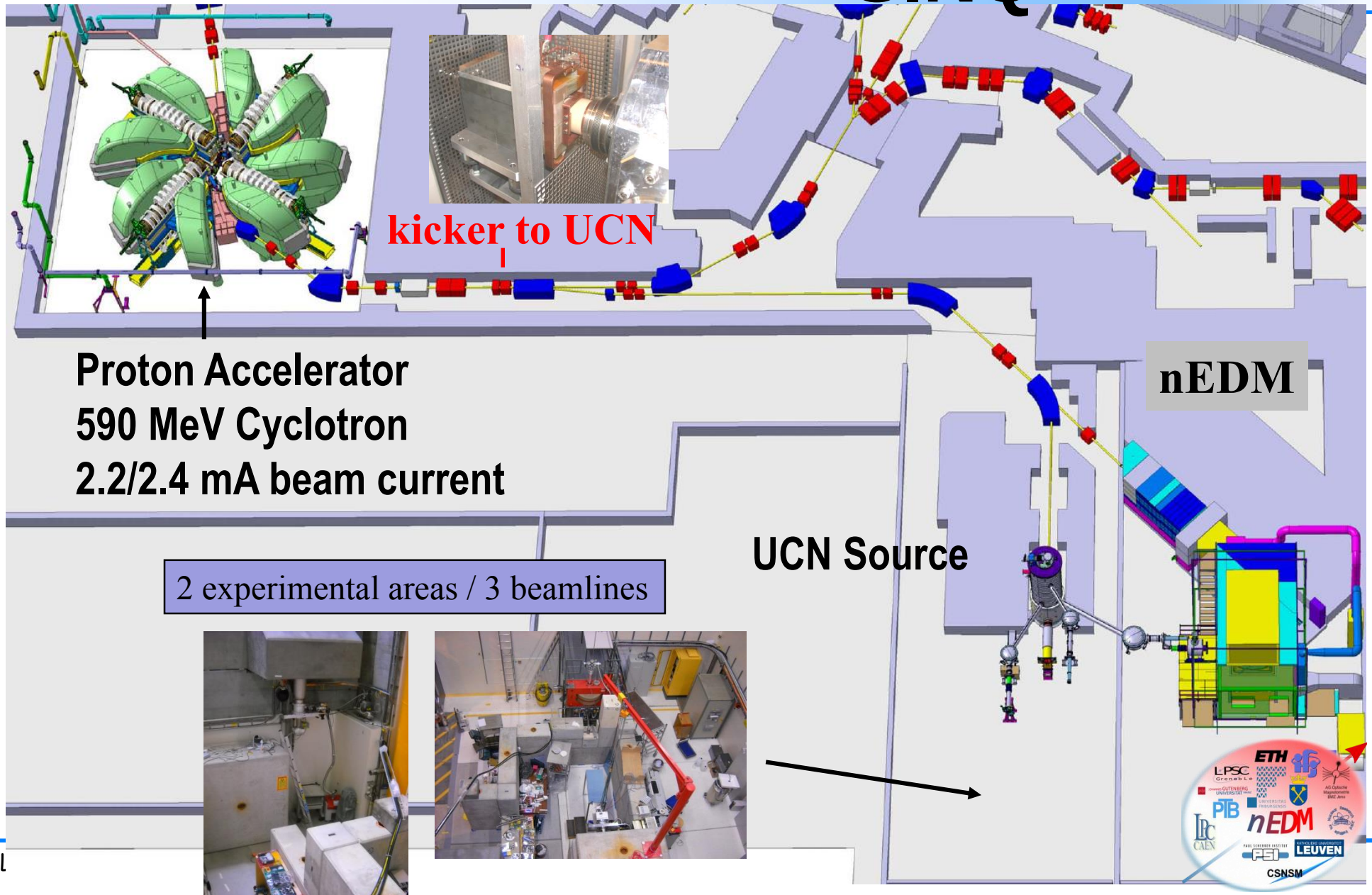
High Intensity Proton Accelerator (HIPA) complex

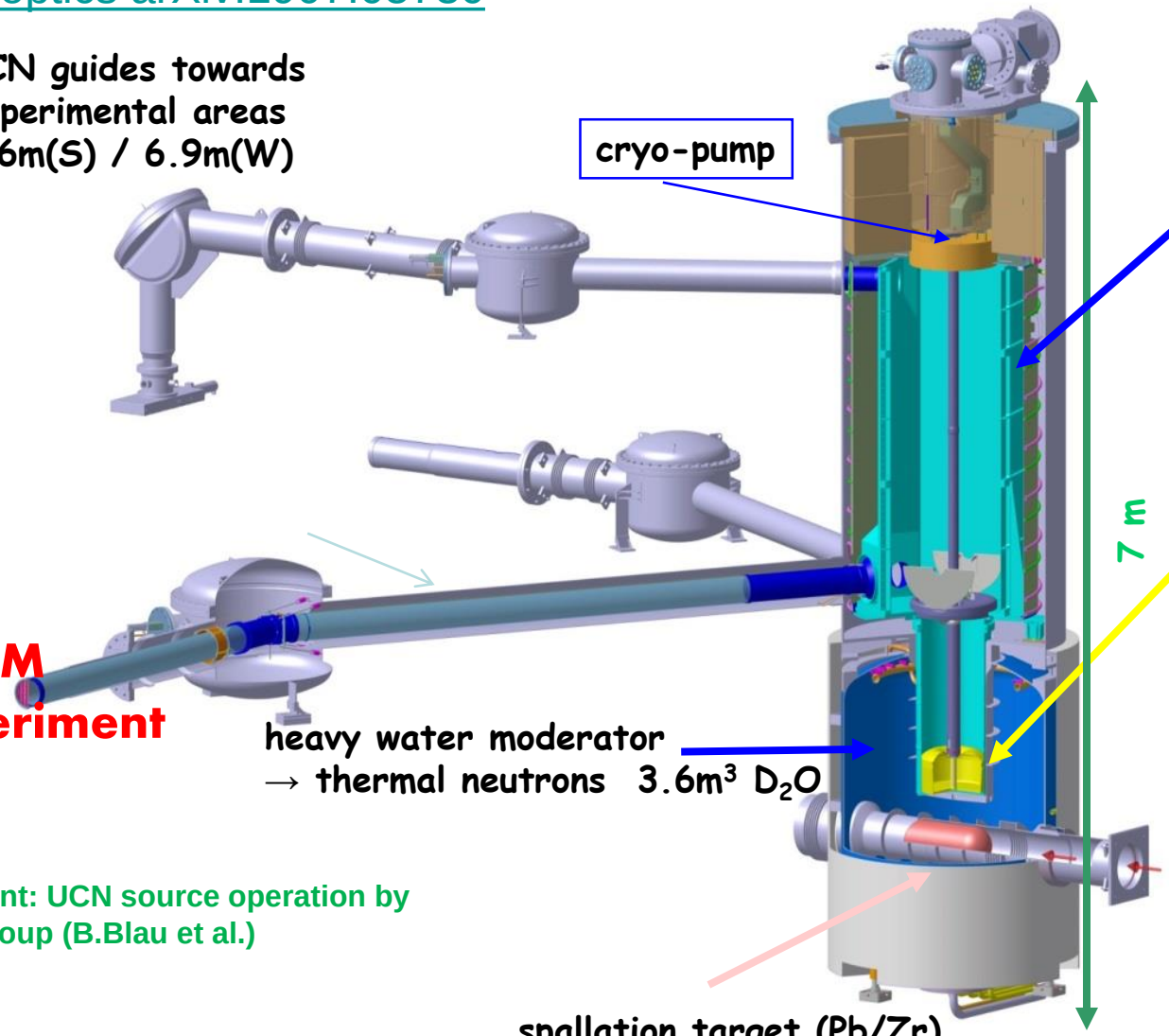
SINQ

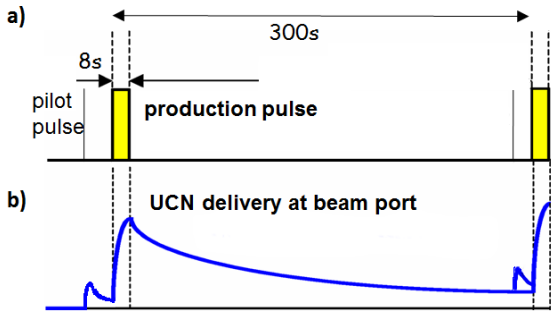
Ultra Cold Neutron Source



The PSI UCN source

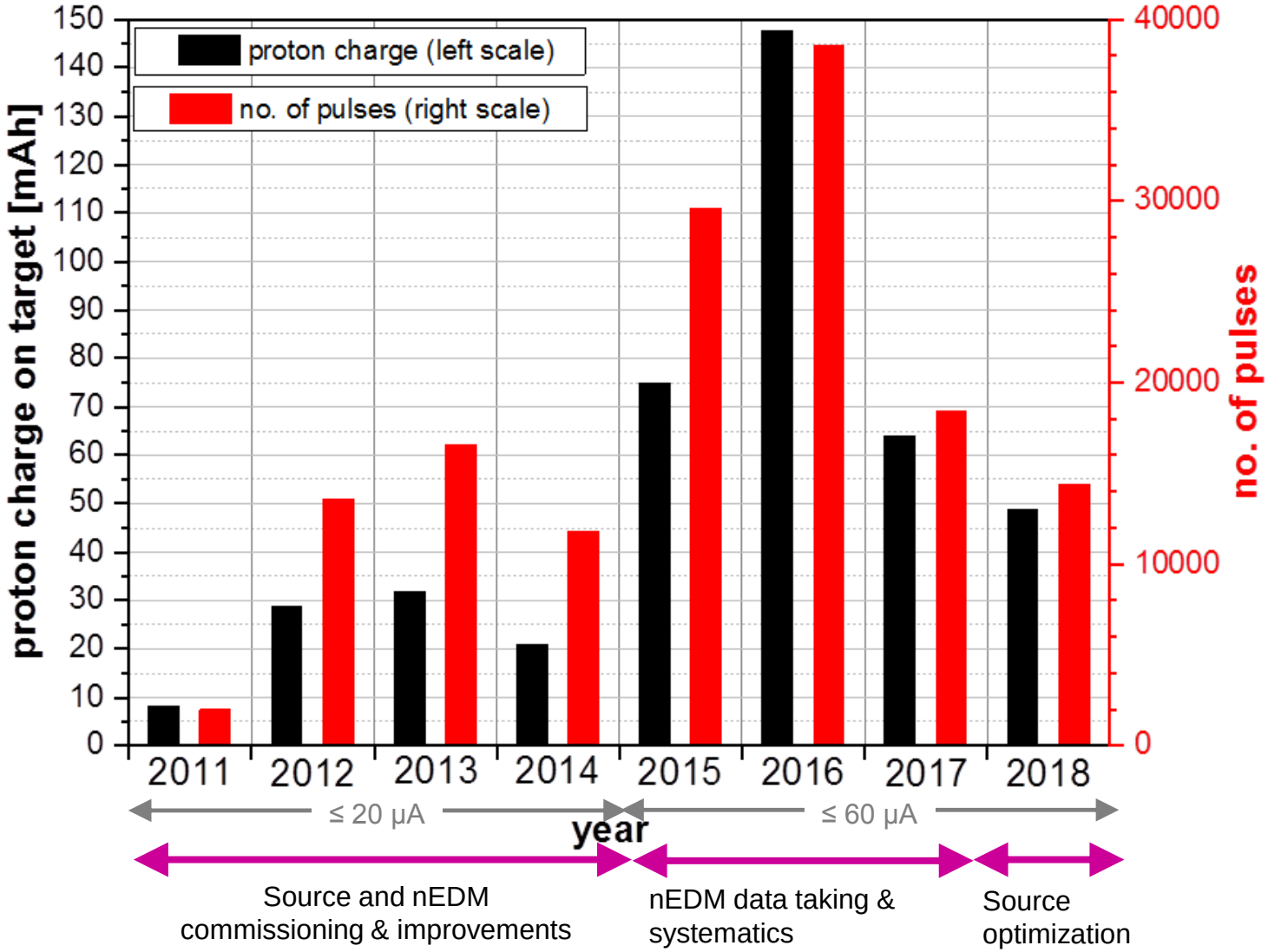
UCN optics arXiv:1907.05730





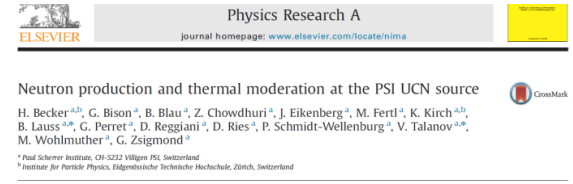
pulsed
1.3 MW p-beam
590 MeV, 2.2 mA,
1% duty cycle

UCN Operations statistics



Understanding the thermal neutron flux

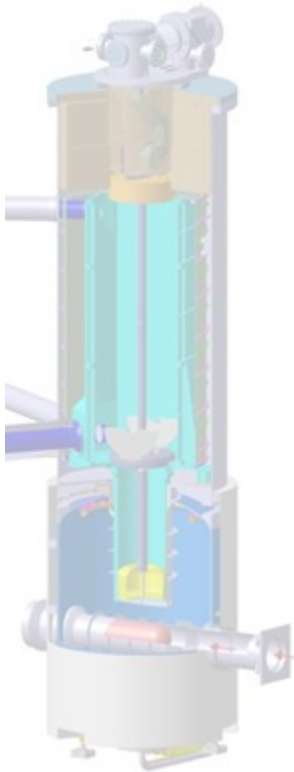
- Fully detailed MCNP-X model and simulation
  by Vadim Talanov + Michael Wohlmuther
- comparison to gold foil measurements


Physics Research A
journal homepage: www.elsevier.com/locate/nima

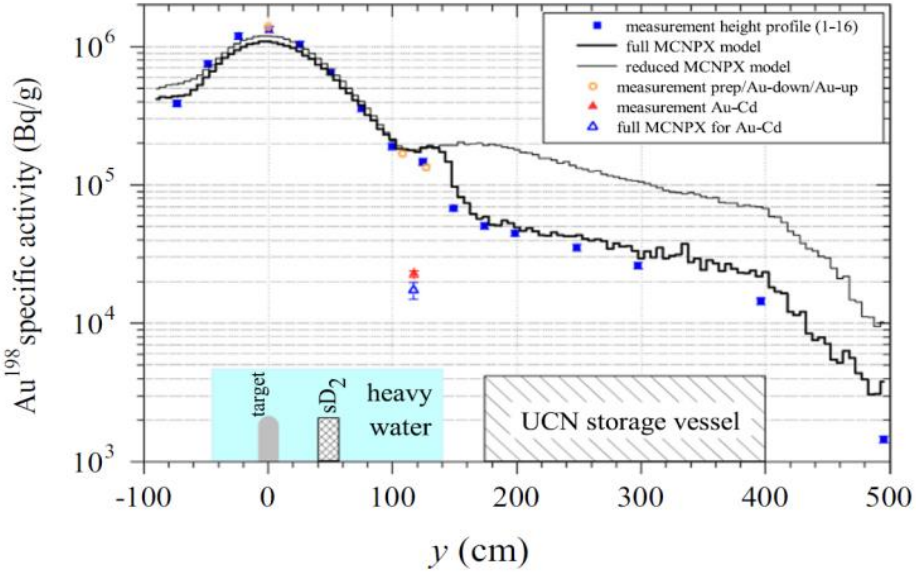
Neutron production and thermal moderation at the PSI UCN source

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]

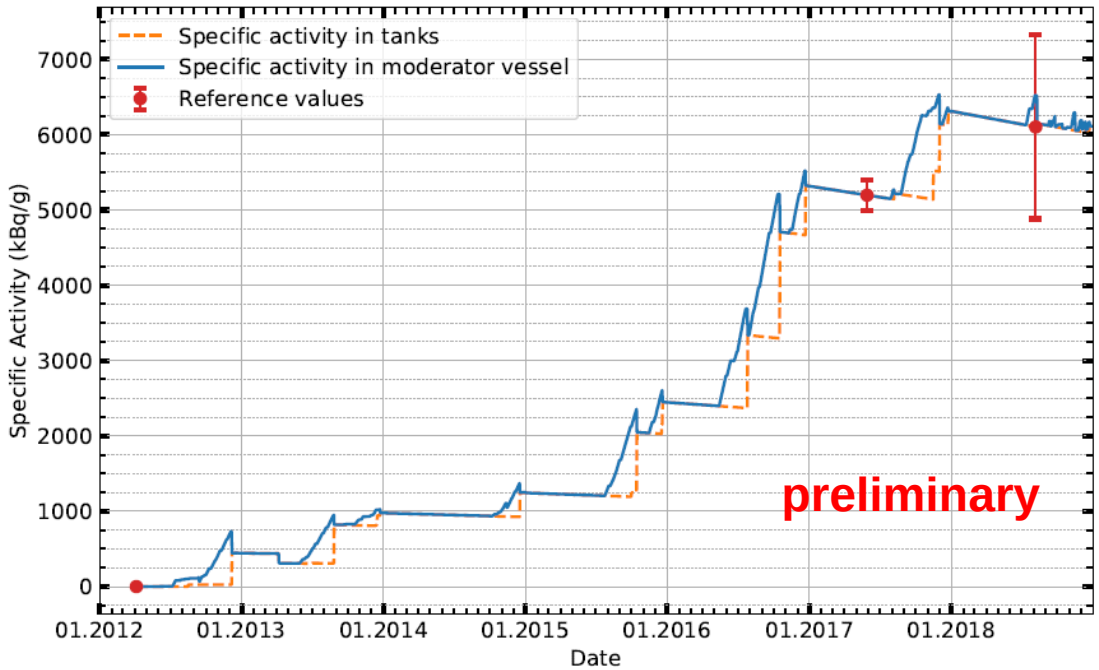
[a] Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland
[b] Institute for Particle Physics, Eidgenössische Technische Hochschule, Zürich, Switzerland



756 Zr/Pb Canelloni Target
~7.5 n/p
by M. Wohlmuther



Understanding the cold flux via tritium activation monitoring



Measurement of tritium in gaseous D2

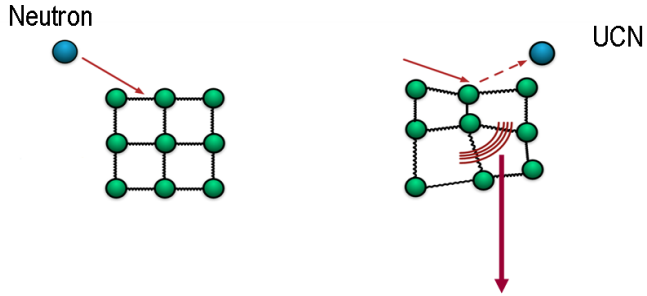
at KIT Karlsruhe - cooperation with Robin Groessle / Tritiumlab

PhD work of Nicolas Hild

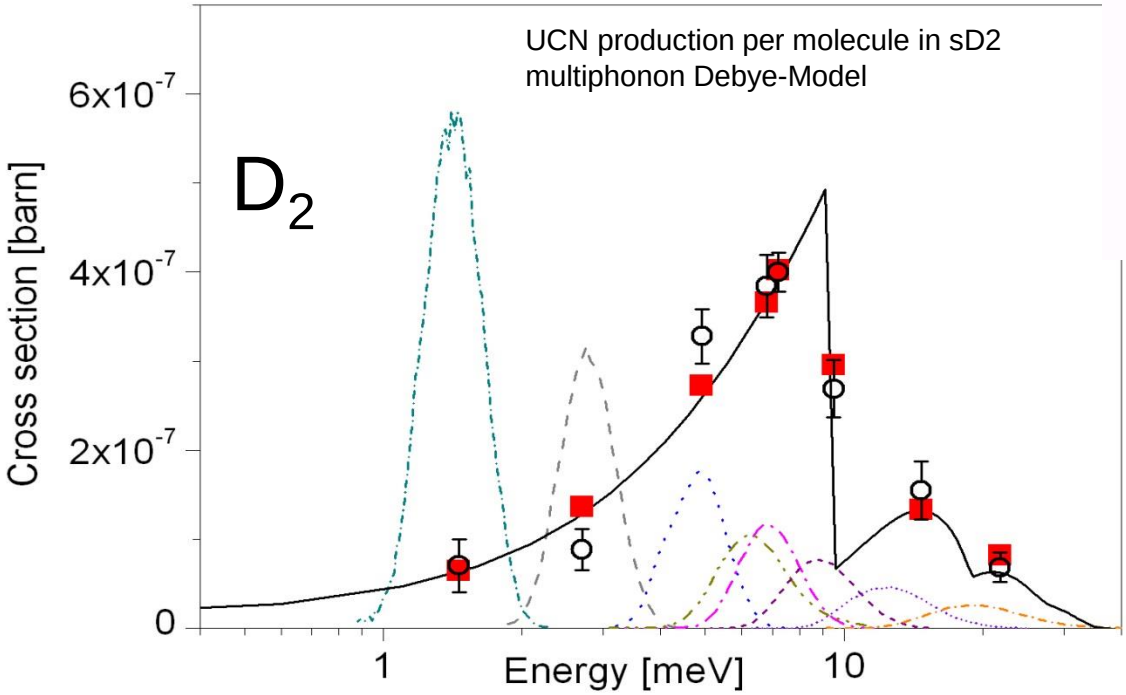
Input - detailed history of
- D2 mass in moderator vessel
- proton beam current

σ-capture ~ $1/v_n$

Why solid deuterium ?
Superthermal UCN production

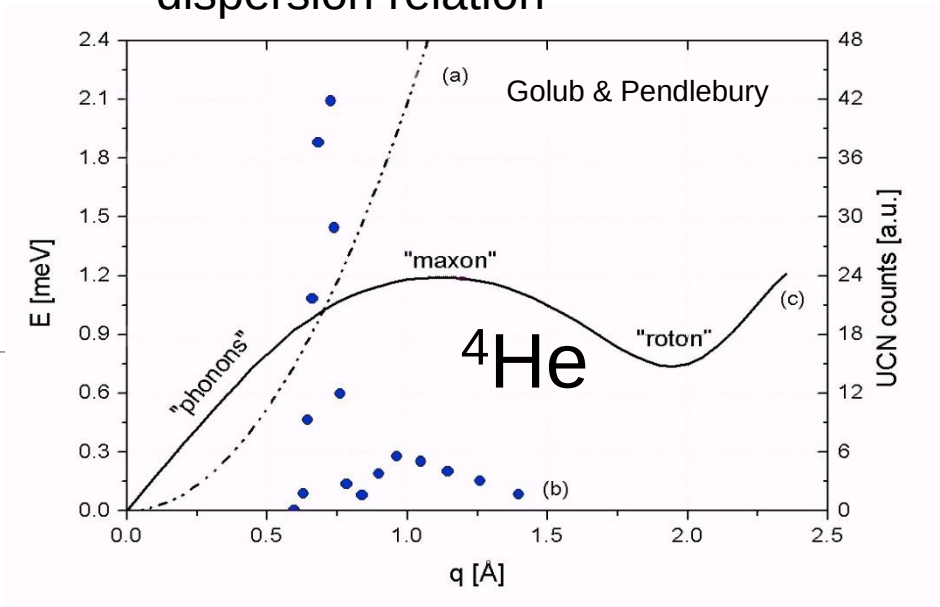


Cooling machine = phonon pump



F. Atchison et al., PRL99(2007)262502 (measurement at SINQ)

dispersion relation

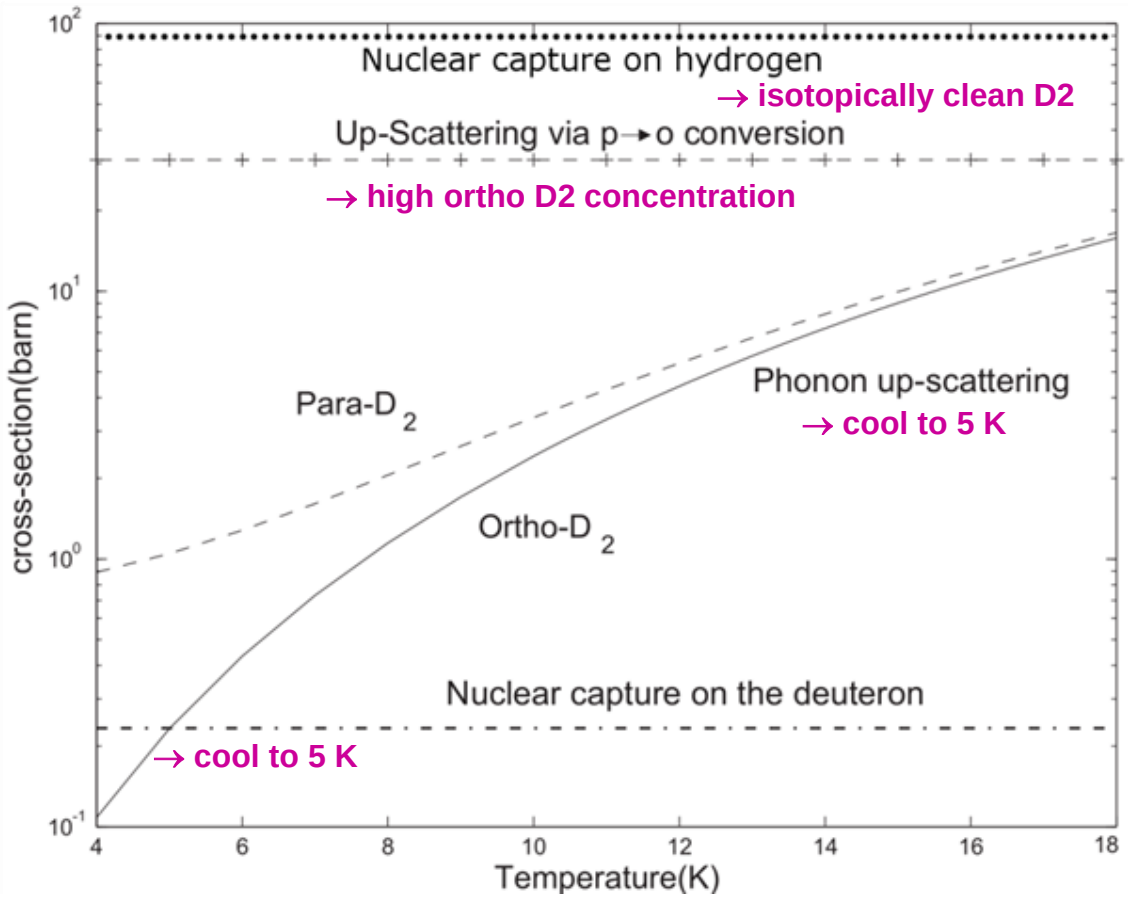


R. *Golub* and J. M. *Pendlebury*, Phys. Lett. 62A (*1977*) 337.

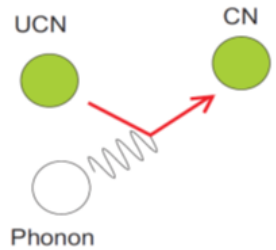
sD2-based UCN sources
at LANL, TRIGA Mainz,
NCSU
and planned for TUM

Beat the losses - go to 5K

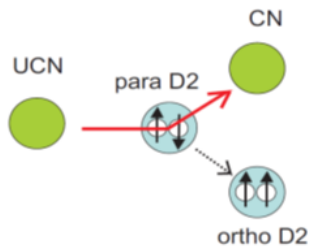
loss cross-sections



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

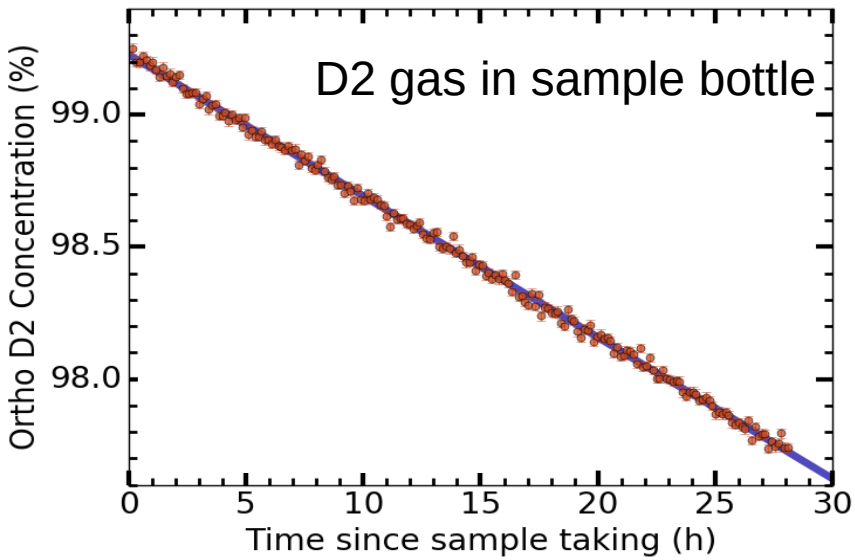


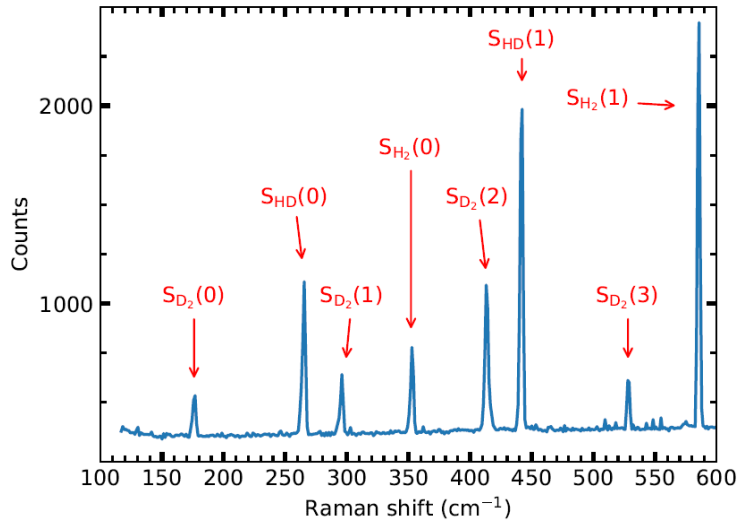
Thermal effect
(better cooling = less losses)



Para Deuterium effect
(less para = less losses)

Raman measurement of: para D2 content and H2/HD content





Result (preliminary):

99.3 % Ortho-D2 (>98%) during standard operation

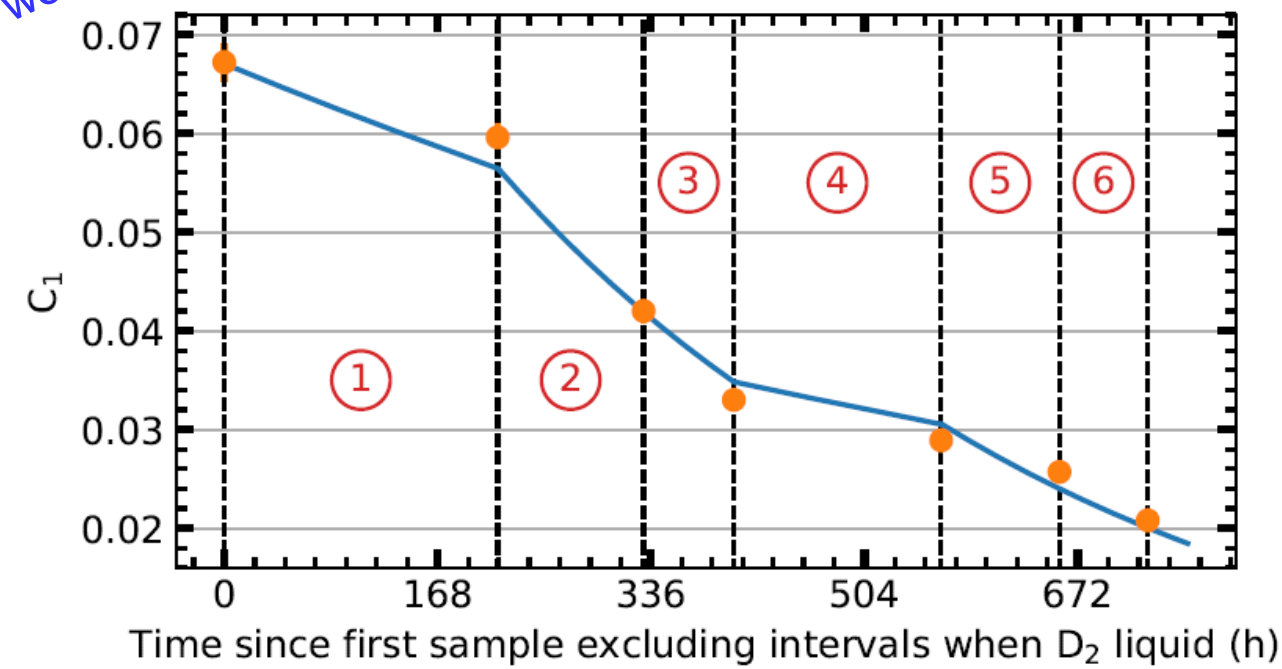
0.33±0.03 % HD-molecules

PhD work of Nicolas Hild

Para-ortho D2 conversion via radiation

preliminary

PhD work of Nicolas Hild

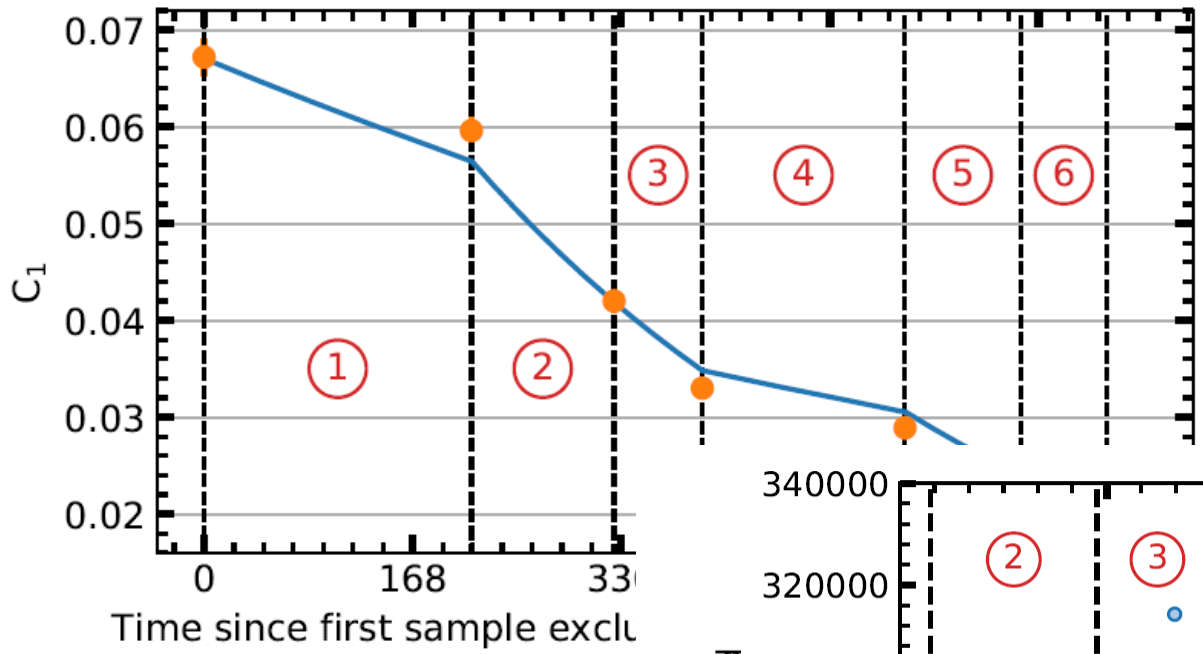


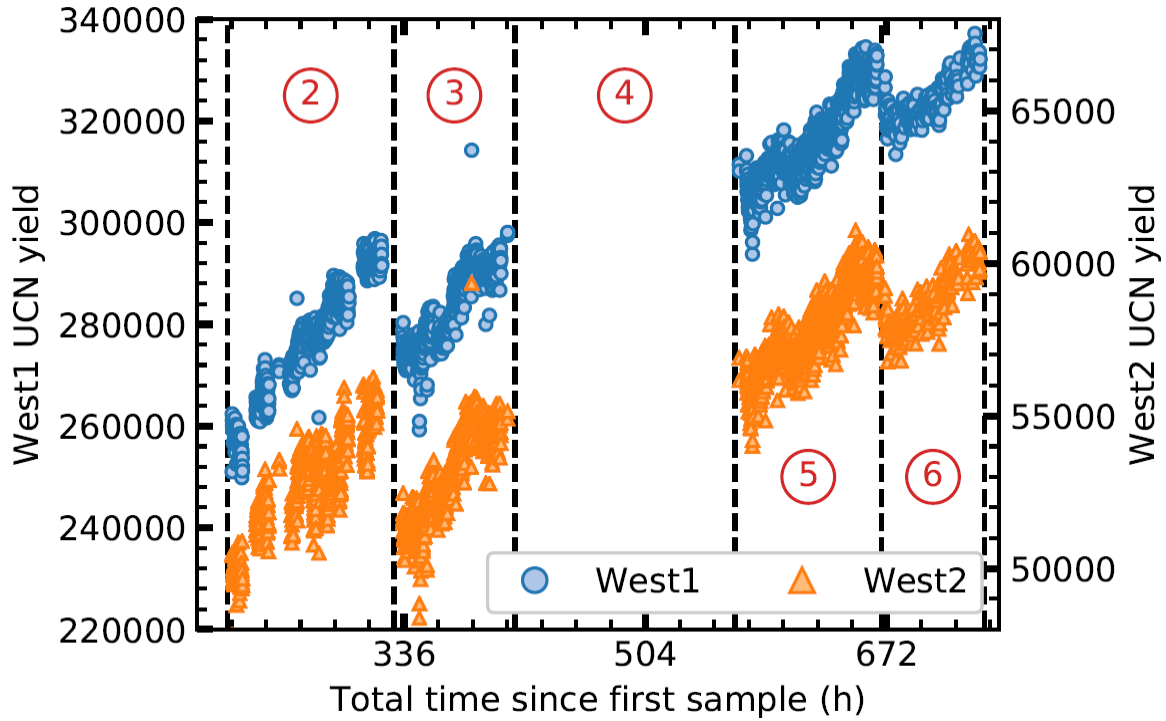
at SINQ - liquid D2 - 76% ortho D2 equilibrium

F. Atchison et al. Phys Rev.B68 (2003) 094114

Para-ortho D2 conversion via radiation

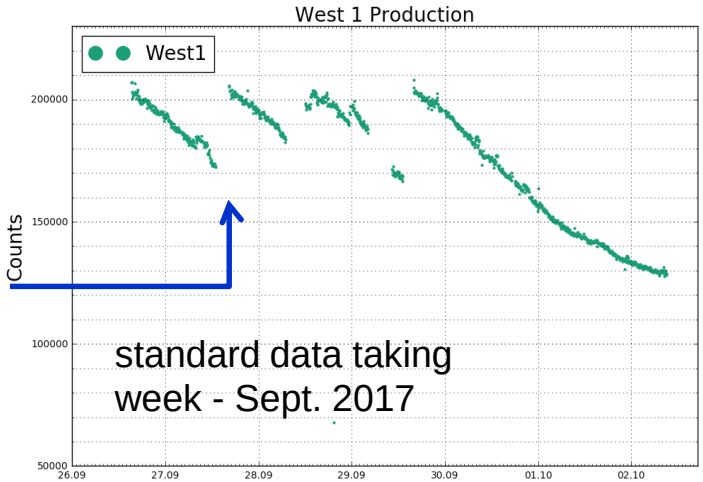
preliminary



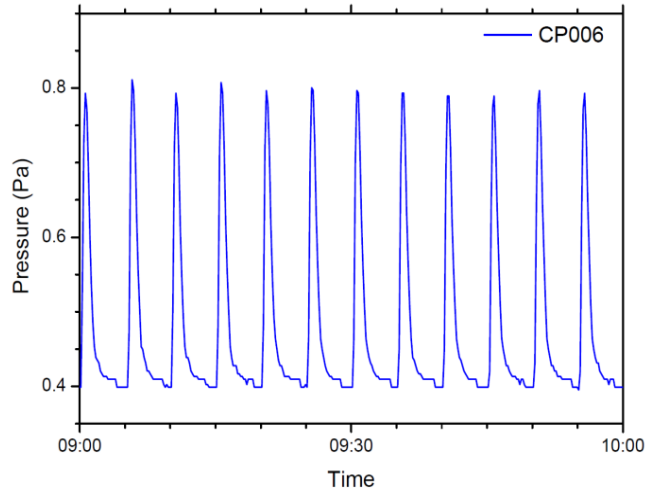


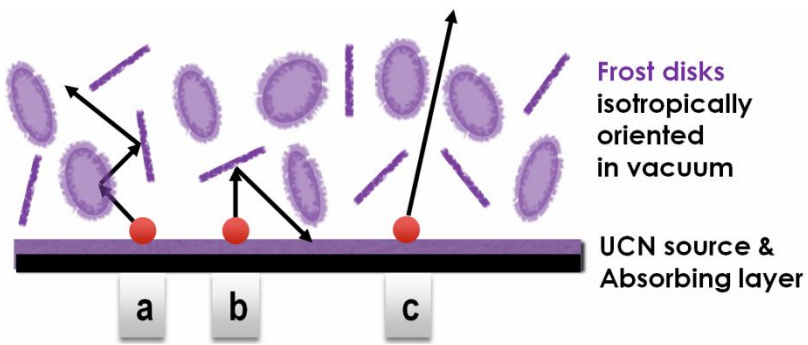
Time behavior of UCN intensity - frost formation

conditioning procedure regains full intensity



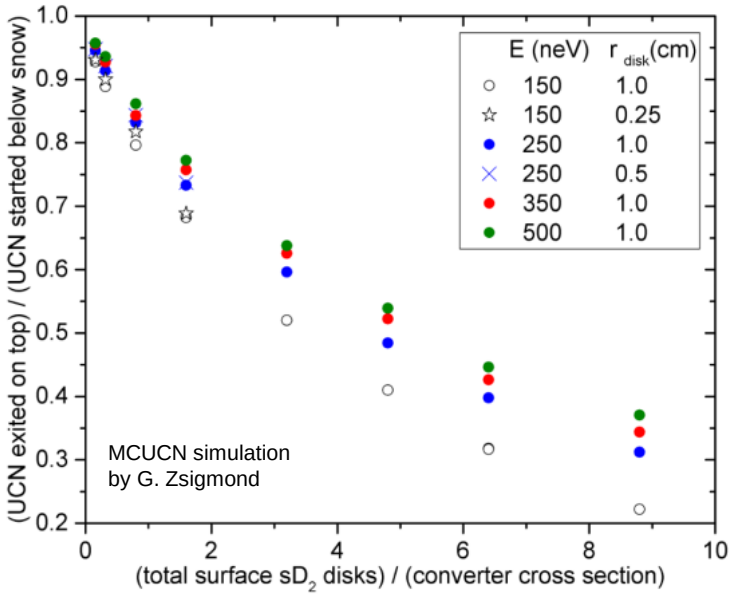
pressure during pulsing





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

Published on 11 September 2018



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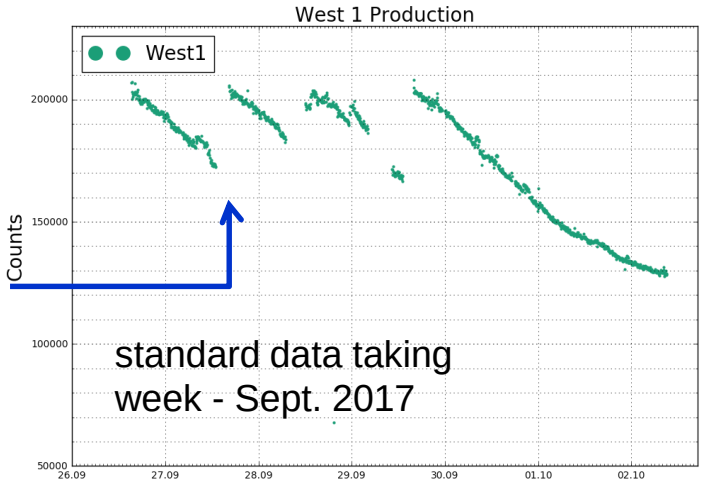

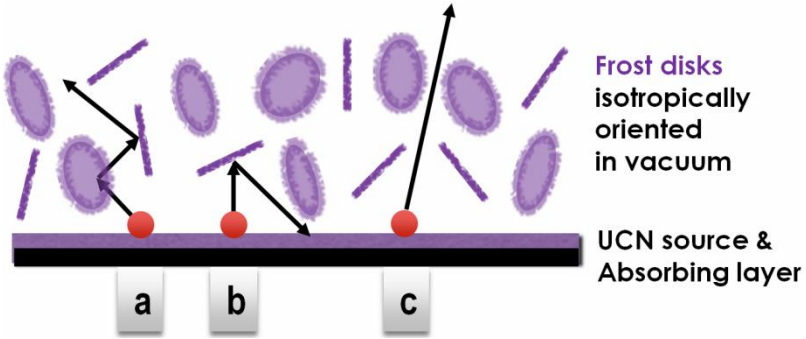

EPJ A Highlight - Solid deuterium surface degradation at ultracold neutron sources

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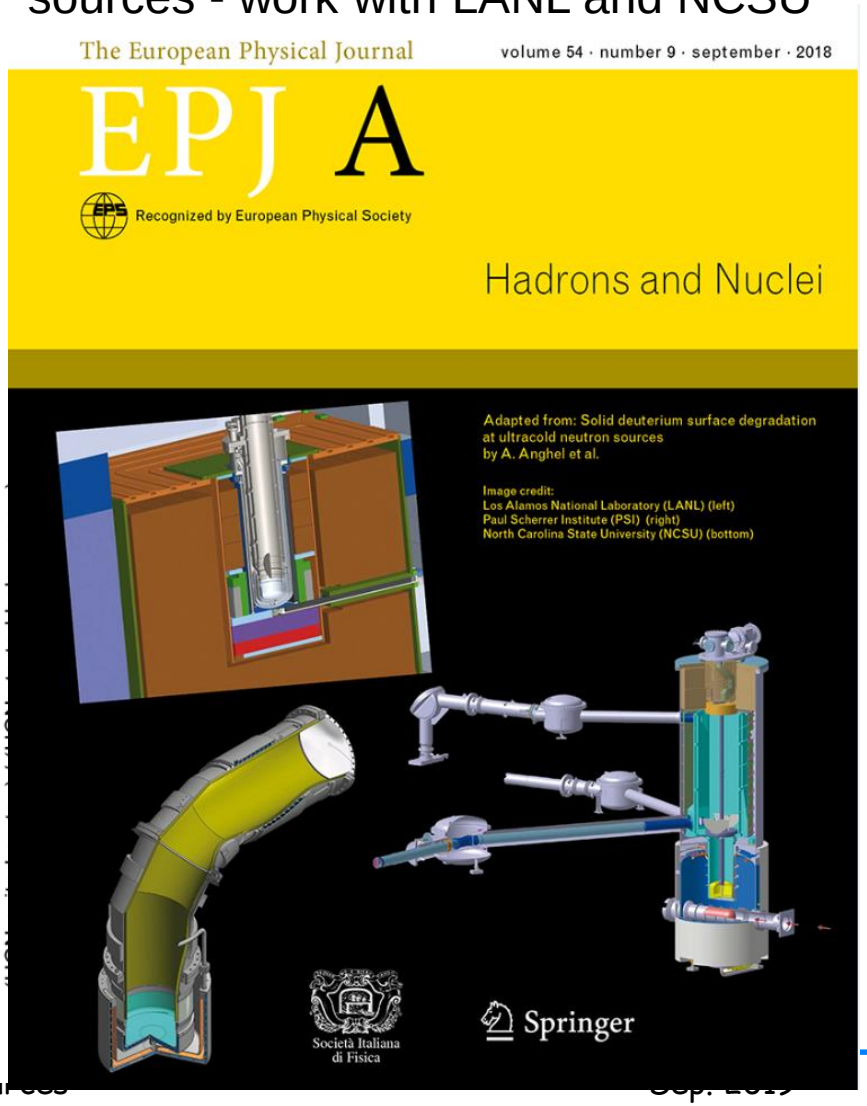
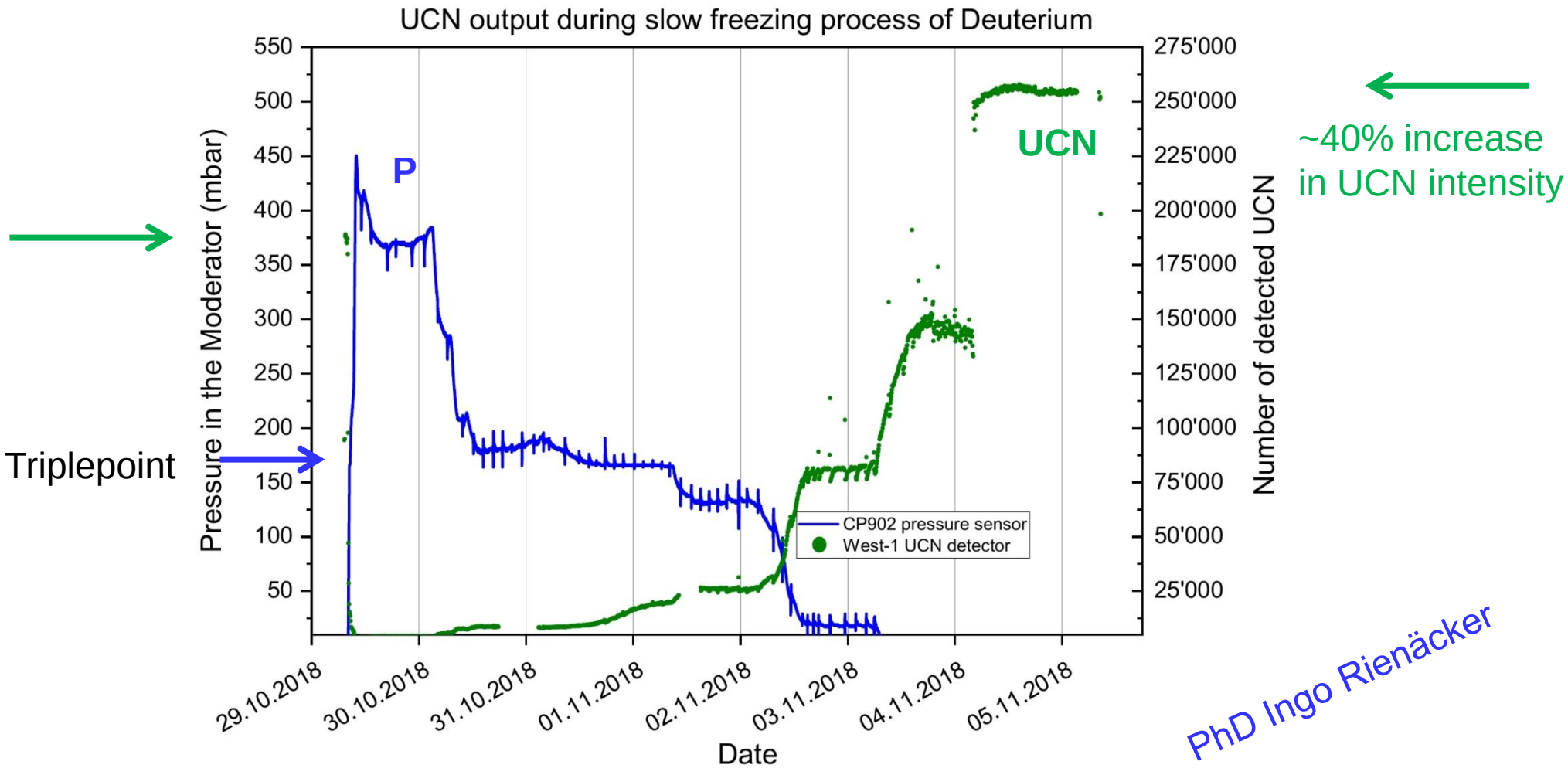
similar effect observed at other UCN sources - work with LANL and NCSU



Slow freeze sD2 test

- longest ever freezing time done at PSI UCN source

preliminary

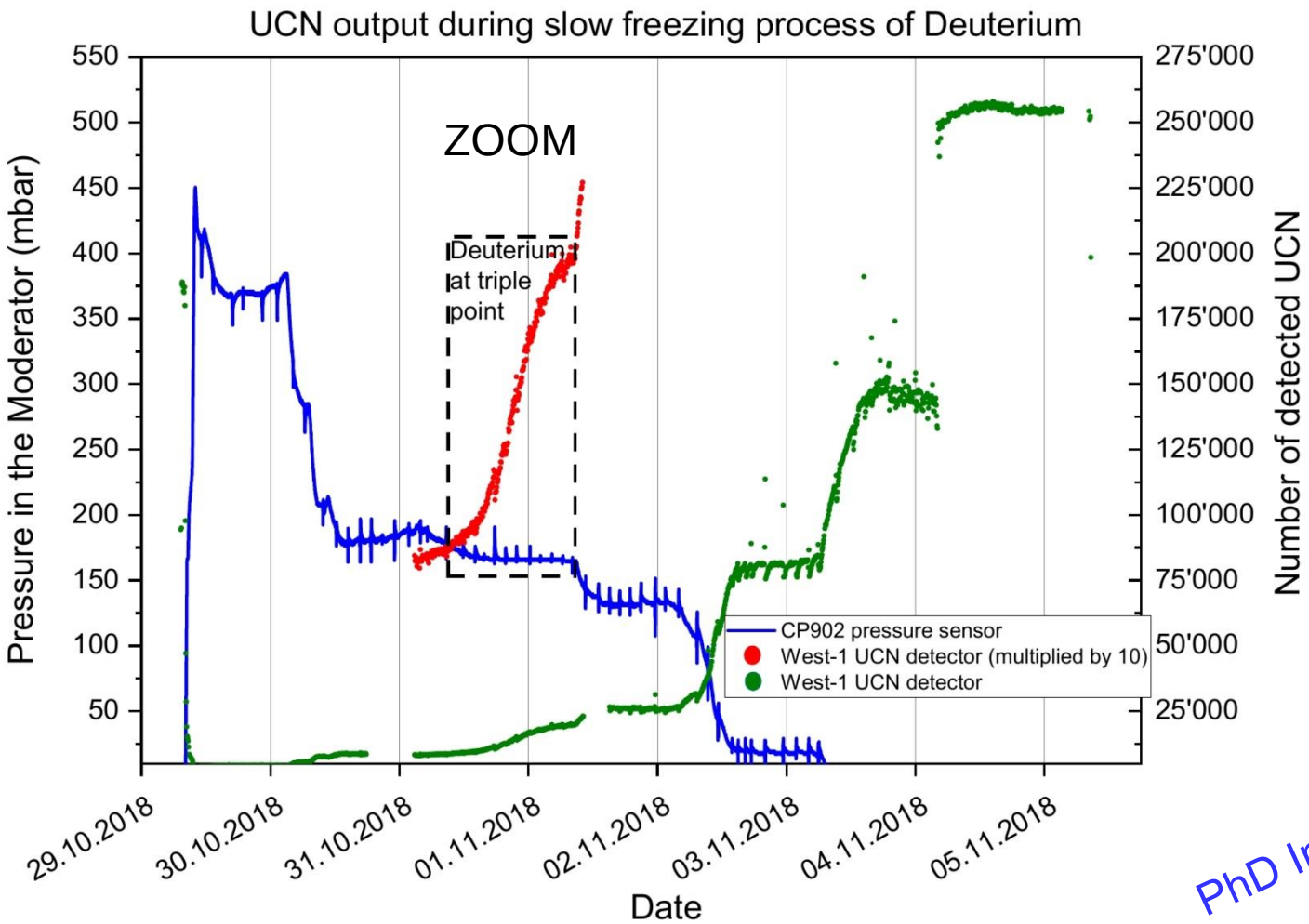


PhD Ingo Rienäcker

Slow freeze sD2 test

- observe behavior of UCN output at the triplepoint (no pressure ambiguity)

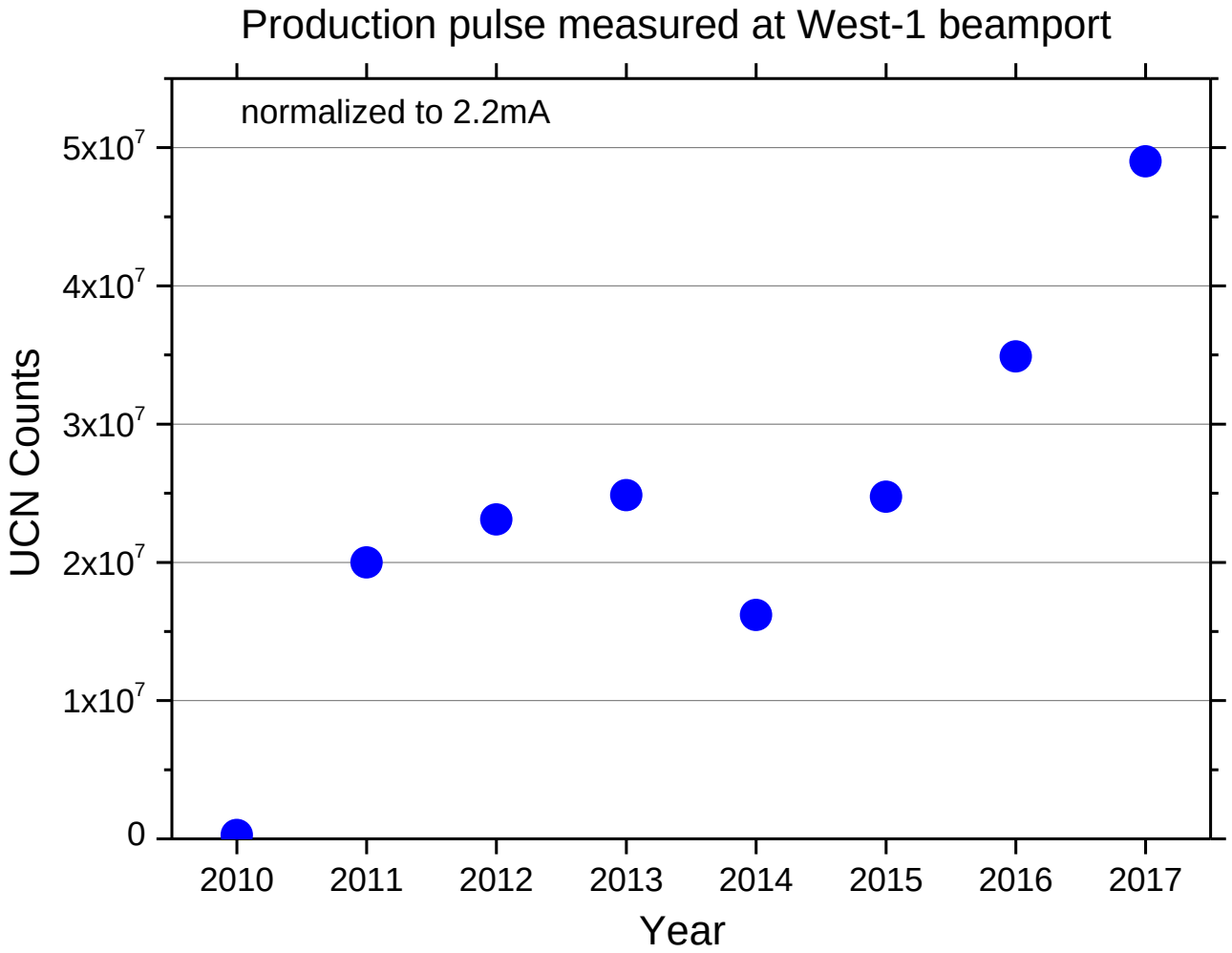
preliminary



PhD Ingo Rienäcker

UCN Source Improvements

highest number of UCN registered at beamport West-1



2018 :
specific
other
studies

Summary:

- **Successful operation of the PSI UCN source has been achieved in the last years - world leading facility.**
- **Better understanding of all source parameters and increase of UCN intensity has been achieved.**
- **Further developments are ahead.**

- **Many thanks to all PhD students for their hard work and to the UCN source operating crew.**

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UCN

Ultra Cold Neutron Source