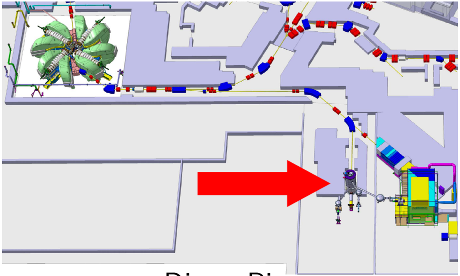
Status of the source for ultracold neutrons at the Paul Scherrer Institute (PSI)

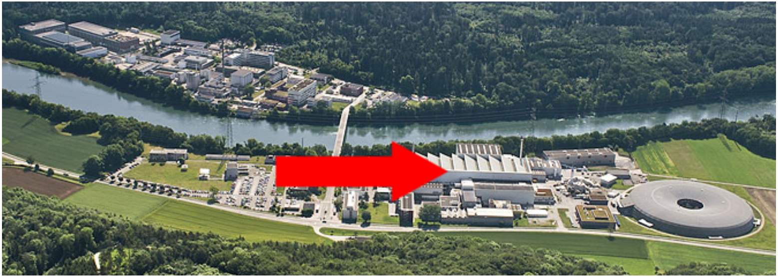


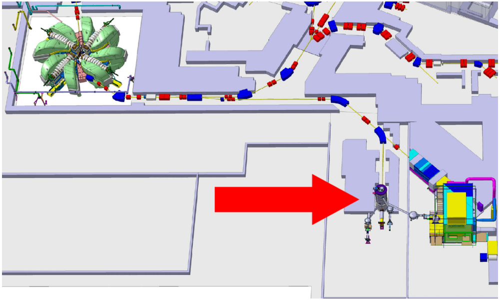
Dieter Ries
on behalf of the PSI UCN project team

ETHZ / UZH PhD Seminar 2014

September 11, 2014

Location





- Paul Scherrer Institut
- 590 MeV proton accelerator
- 2.2 mA beam current
- 1 % dutycycle

Ultracold Neutrons (UCN)

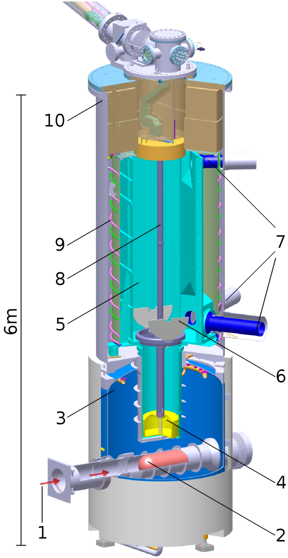
Ultracold:

$E_{\text{kin}} < 350\,\text{neV} \Leftrightarrow v < 8\,\text{m}\,\text{s}^{-1} \Leftrightarrow \lambda > 140\,\text{nm} \Leftrightarrow T < 4.1\,\text{mK}$

Why?

- Materials with effective wall potentials up to 335 neV ($^{58}\mathrm{Ni}$)
- Storage of UCN by total reflection under any angle of incidence
- Storage times comparable to the free neutron lifetime
- Research on free neutrons with long observation time

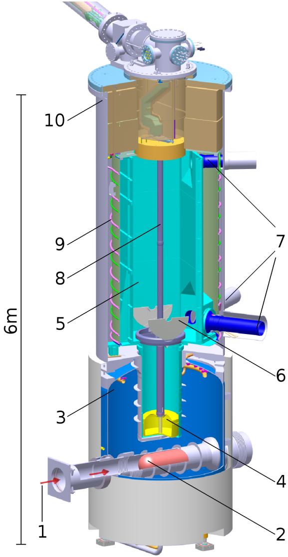
UCNS@PSI



1. PSI PB, up to 8 s p
2. ST (Pb)
3. D_2OV
4. 30 dm^3 sD_2M
5. ~2 m^3 UCN-SV, DLC C
6. SVS
7. UCNg
   - ~ 8 m
   - NiMoC
8. He and D_2 SLs
9. TS
10. VT

DG: 1000 UCN/cm^3 in a TESV.

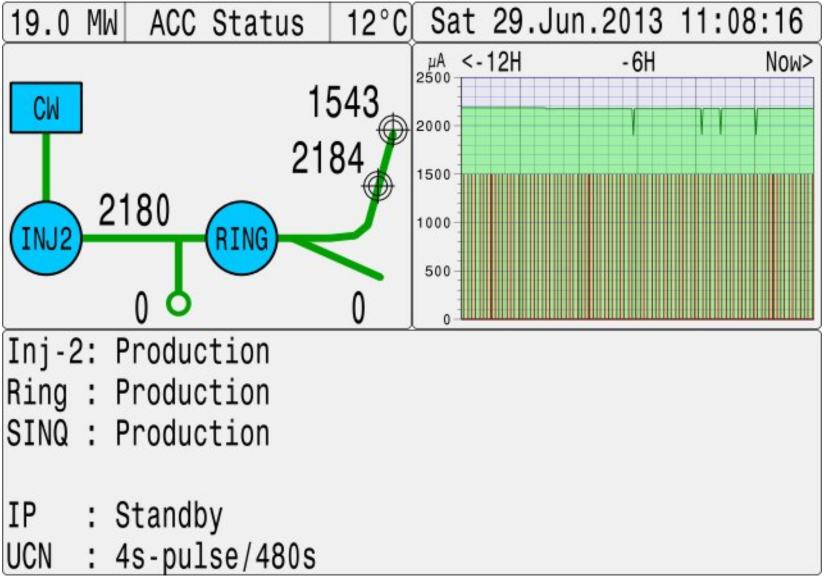
The UCN source at PSI



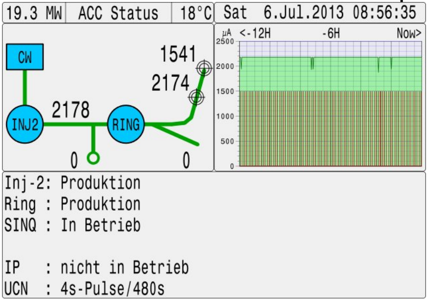
1. PSI proton beam, up to 8 s pulses
2. Spallation target (Pb)
3. D_2O vessel
4. 30 dm^3 solid D_2 moderator
5. ~2 m^3 UCN storage vessel, Diamond like Carbon (DLC) coating
6. Storage vessel shutter
7. UCN guides towards experiments
   - ~ 8 m long
   - coated with NiMo
8. He and D_2 supply lines
9. Thermal shield
10. Vacuum tank

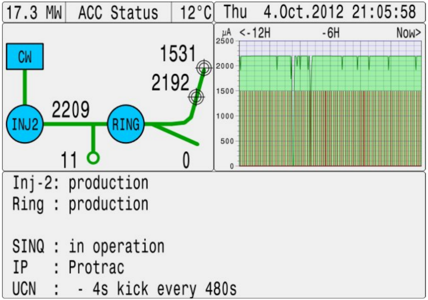
Design goal: 1000 UCN/cm^3 in a typical external storage volume.

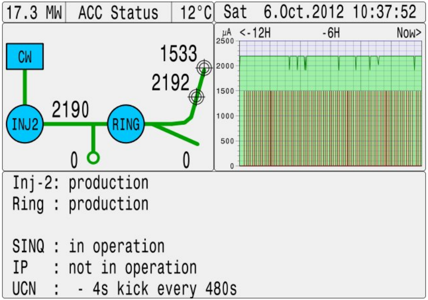
In regular operation since 2012

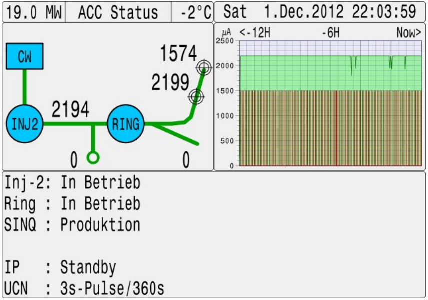


in operation 2



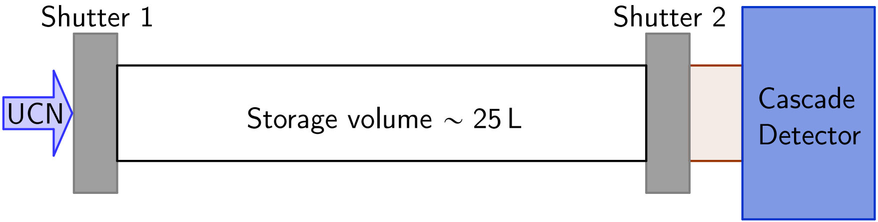




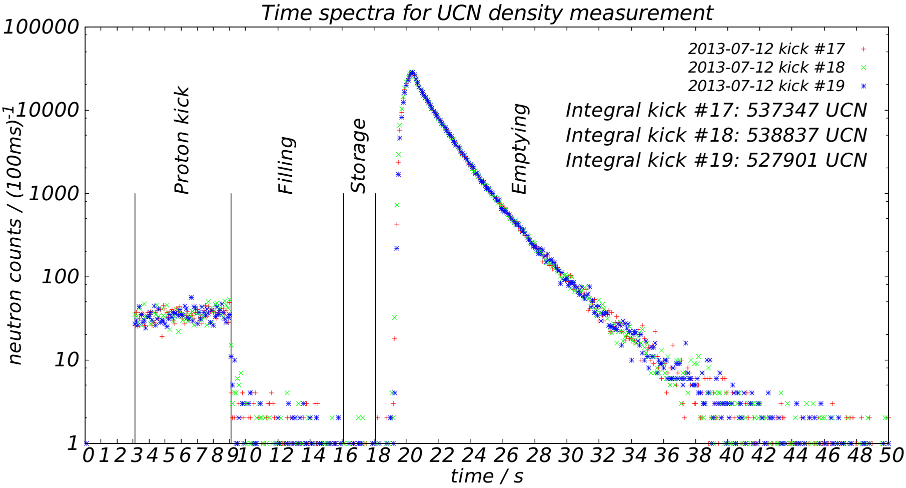


Measurement of the UCN Density 1

- Measured in July 2013 at the west-1 beamport of the UCN source.
- Storage volume: 1 m long glass tube, inside diameter 180 mm.
- Wall coating: 500 nm NiMo, optical potential $\sim$ 220 neV.
- Shutter coating: Diamond like carbon, optical potential $\sim$ 230 neV.



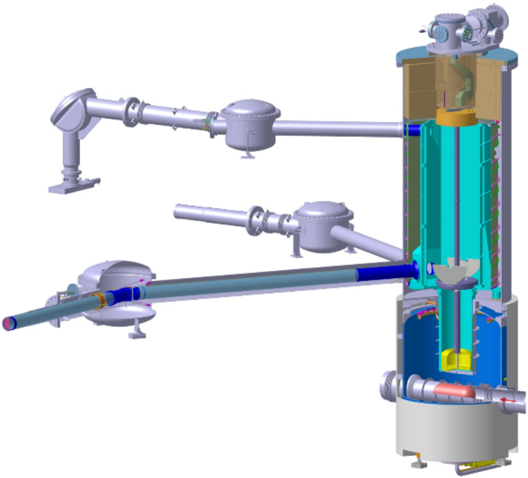
Measurement of the UCN Density 2



Measurement of the UCN Density 3

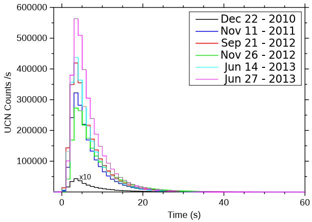
- Storage volume: 25 447 cm^3.
- Measured 21.0(2) UCN/cm^3 after 2 s storage.
- Transmission of AlMg3 detector entrance window: $\lesssim 70\,\%$.
- Total UCN density at beamport: 30 UCN/cm^3 after 2 s storage.

Understanding and improving UCN performance



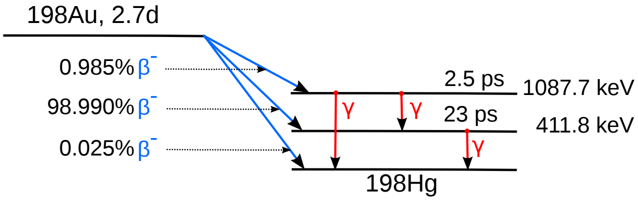
Approach:

- measure performance of each subsystem
- verify model predictions
- exclude neutron loss



Gold activation measurements

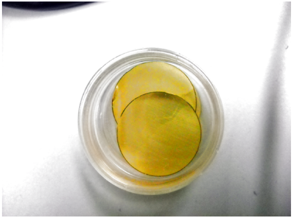
- Well known technique to measure thermal neutron fluxes.
- Neutron capture: $^{197}\mathrm{Au} + n \rightarrow {}^{198}\mathrm{Au}$.
- Subsequent beta decay, $\tau \simeq 2.7\,\mathrm{d}$.



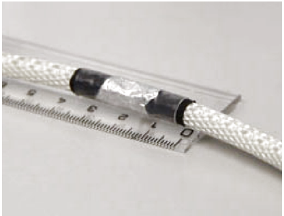
- Gamma spectroscopy used to determine initial activation.
- Derive flux of neutrons through foil from activation, foil mass, expected neutron energy spectrum.

Gold activation measurements 2

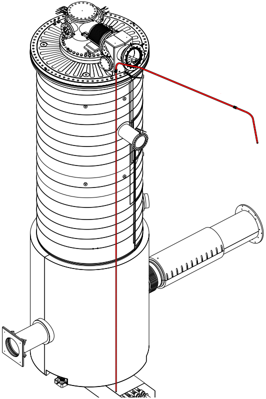
- 16 Au foils, 25 μm thick, in vertical tube along vacuum tank.
- Irradiated during one 2 s proton beam kick.
- Standard foil geometry, circular, radius 12.5 mm, calibrated solid angle in detector.
- Mass: $\mathcal{O}(250\,\mathrm{mg})$



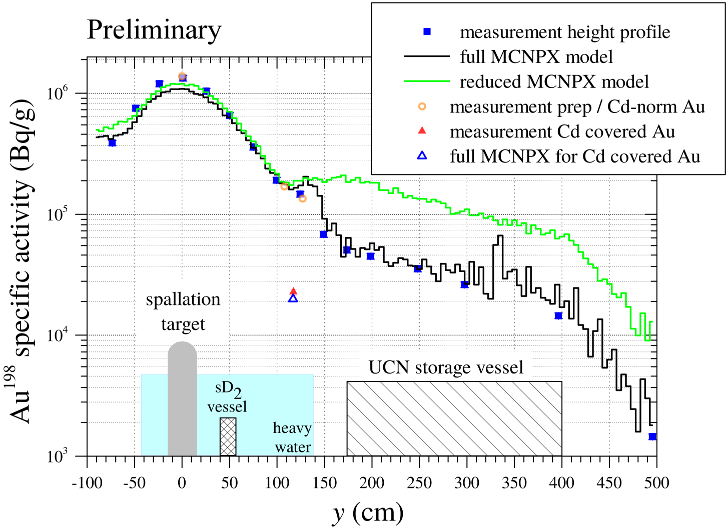
Gold foils, laser cut.



Nylon rope assembly.



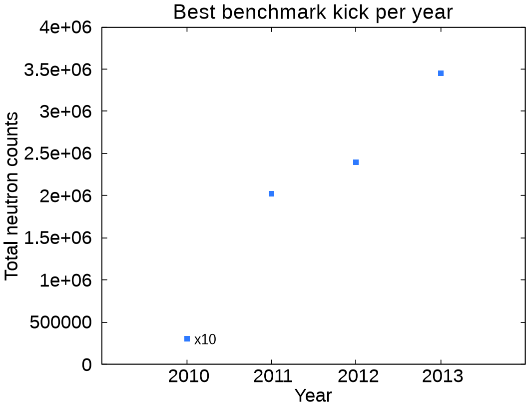
Comparison to MCNPX calculations



arXiv:1408.3217 [nucl-ex]

Continuous improvements

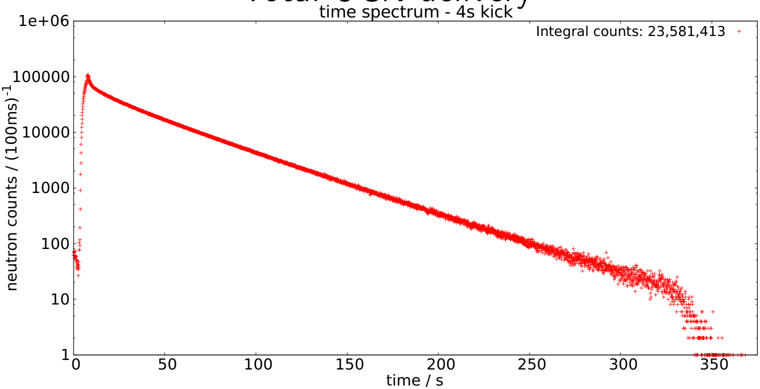
- New He valves since 2012: Better control of the coolant flow.
- More D_2 in the system since 2013: Increased cold neutron flux.
- Optimised proton beam tune:
  - Smaller proton beam size: Less losses at collimators.
  - Beam center above target axis: Increased neutron flux in D_2.



Ongoing UCN program

- Optimisation of $\mathrm{D_2}$ freezing process.
- Optimisation of the storage vessel shutter timing
- Validation of UCN Monte Carlo simulations.
- Characterisation of various parts of the source:
    - UCN guides
    - Storage volume.
    - Window transmission
- Measurement of the cold neutron flux in the solid $\mathrm{D_2}$.
- Optimisation of shutter timing.
- Feed nEDM experiment at beamport south.
- Test experiments, e.g. UCN detector tests, at beamport west-2.
- World-wide comparison of UCN source performance in room temperature experiments

Total UCN delivery



Total number of UCN, 4 s proton beam kick: $\sim 23 \times 10^6$ UCN.
Repetition frequency: $\sim 180\,\mathrm{d}^{-1}$.

$$\text{Total:} \quad \sim 4 \times 10^9\,\mathrm{UCN/d}$$

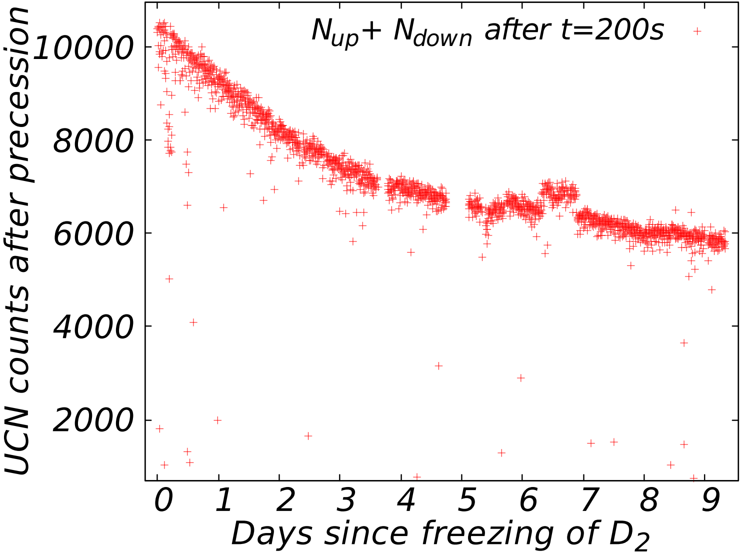
Conclusions

- The UCN source at the Paul Scherrer Institut is in regular operation.
- Presently a UCN density of 30 UCN/cm^3 can be measured at the beamport.
- Characterisation and improvement program is ongoing.
- Improvements of up to an order of magnitude may still be feasible.
- Experiments at the beamports are regularly supplied with UCN.

Thank you for your Attention

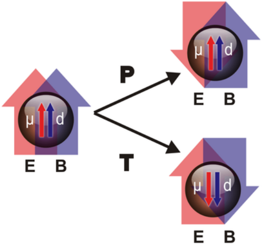
Backup

UCN intensity vs time



Motivation: Neutron Electric Dipole Moment

Non-zero neutron electric dipole moment: Violation of CP symmetry!



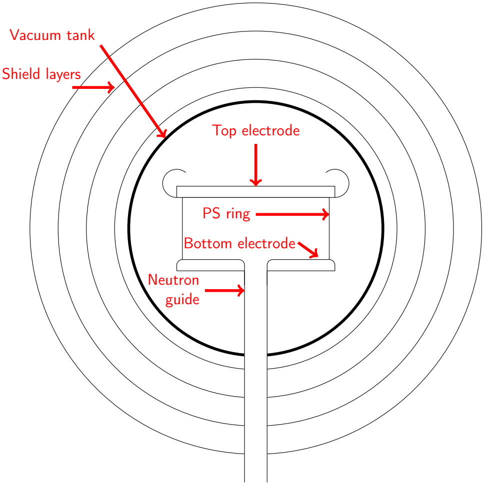
$$\mathscr{H} = -d\frac{\vec{\sigma}}{|\vec{\sigma}|}\vec{E} - \mu\frac{\vec{\sigma}}{|\vec{\sigma}|}\vec{B} \neq d\frac{\vec{\sigma}}{|\vec{\sigma}|}\vec{E} - \mu\frac{\vec{\sigma}}{|\vec{\sigma}|}\vec{B}$$

- Measurement technique: Precession of stored ultracold neutrons (UCN) in electric and magnetic field.
- Comparison of Ramsey precession frequencies in parallel and antiparallel field configuration:

$$d_n = \frac{\hbar\Delta\omega + 2\mu_n(\overrightarrow{B_{\uparrow\uparrow}} - \overrightarrow{B_{\uparrow\downarrow}})}{\overrightarrow{E_{\uparrow\uparrow}} - \overrightarrow{E_{\uparrow\downarrow}}}$$

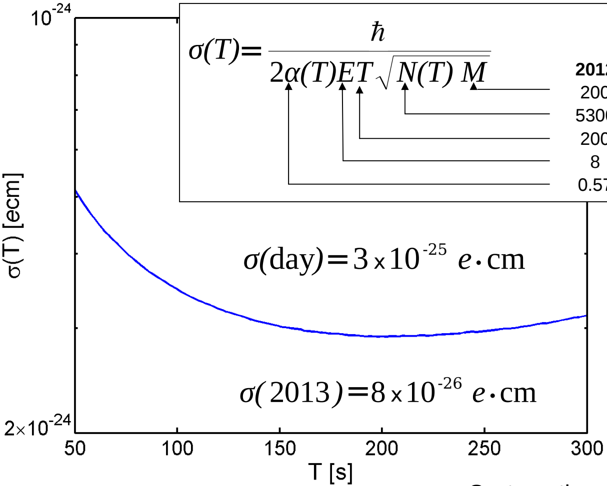
The nEDM experiment at PSI

- Two aluminium electrodes.
- Insulating ring, ∅460 mm.
- Vacuum tank.
- Magnetic shielding.
- Neutrons filled in from below.
- Ultracold: $E_{\text{kin}} \lesssim 250\,\text{neV}$



nEDM performance at beamport south

Expected daily sensitivity as function of free precession time T:



$$\sigma(T) = \frac{\hbar}{2\alpha(T) E T \sqrt{N(T)\, M}}$$

2012	2013	Avg
200	210	cycles
5300	7000	$N_u + N_d$
200	180	s
8	10.2	kV/cm
0.57	0.58	

$$\sigma(\text{day}) = 3 \times 10^{-25}\ e \cdot \text{cm}$$

$$\sigma(2013) = 8 \times 10^{-26}\ e \cdot \text{cm}$$

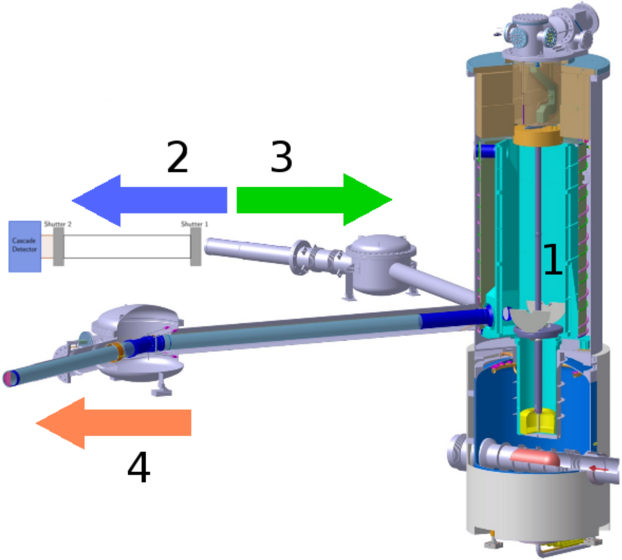
Approximately same sensitivity as Baker et al. [1] at ILL.

Goal 2013: 90 days

Systematics see poster P.N. Prashanth

[1] Baker et al. PRL(2006) 131801

"Ping-Pong": Characterisation of the guide system



- Produce UCN
- Store at one beamport
- Empty source volume
- Release UCN towards source
- Detect at other beamport

"Ping-Pong" vs MC