Performance of the ultracold neutron source at the Paul Scherrer Institute

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Paul Scherrer Institute

on behalf of the PSI UCN Team

Contents

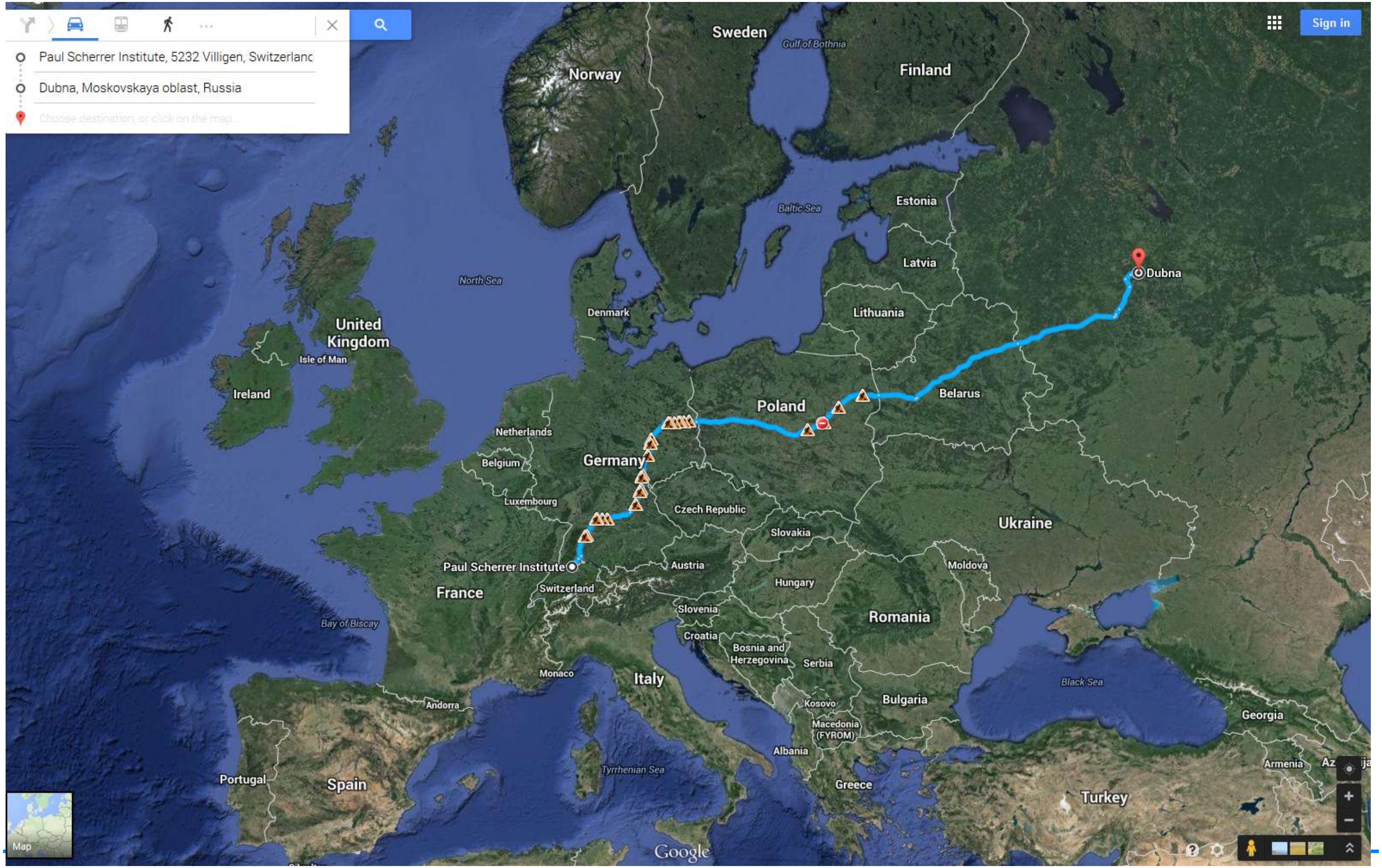
- Introduction to PSI

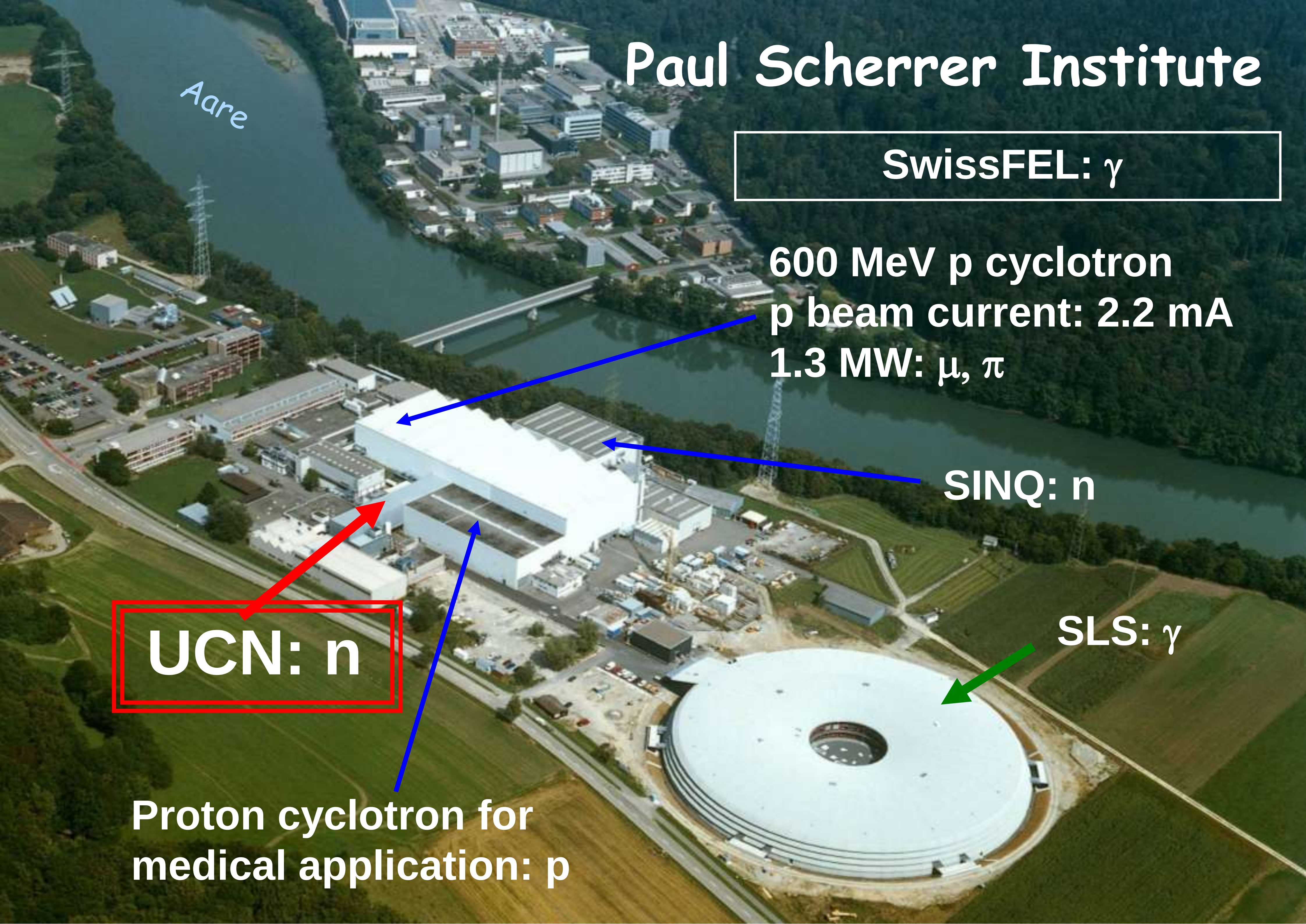
- Introduction to the ultracold neutron source,
  - construction
  - operation

- Performance with ultracold neutrons

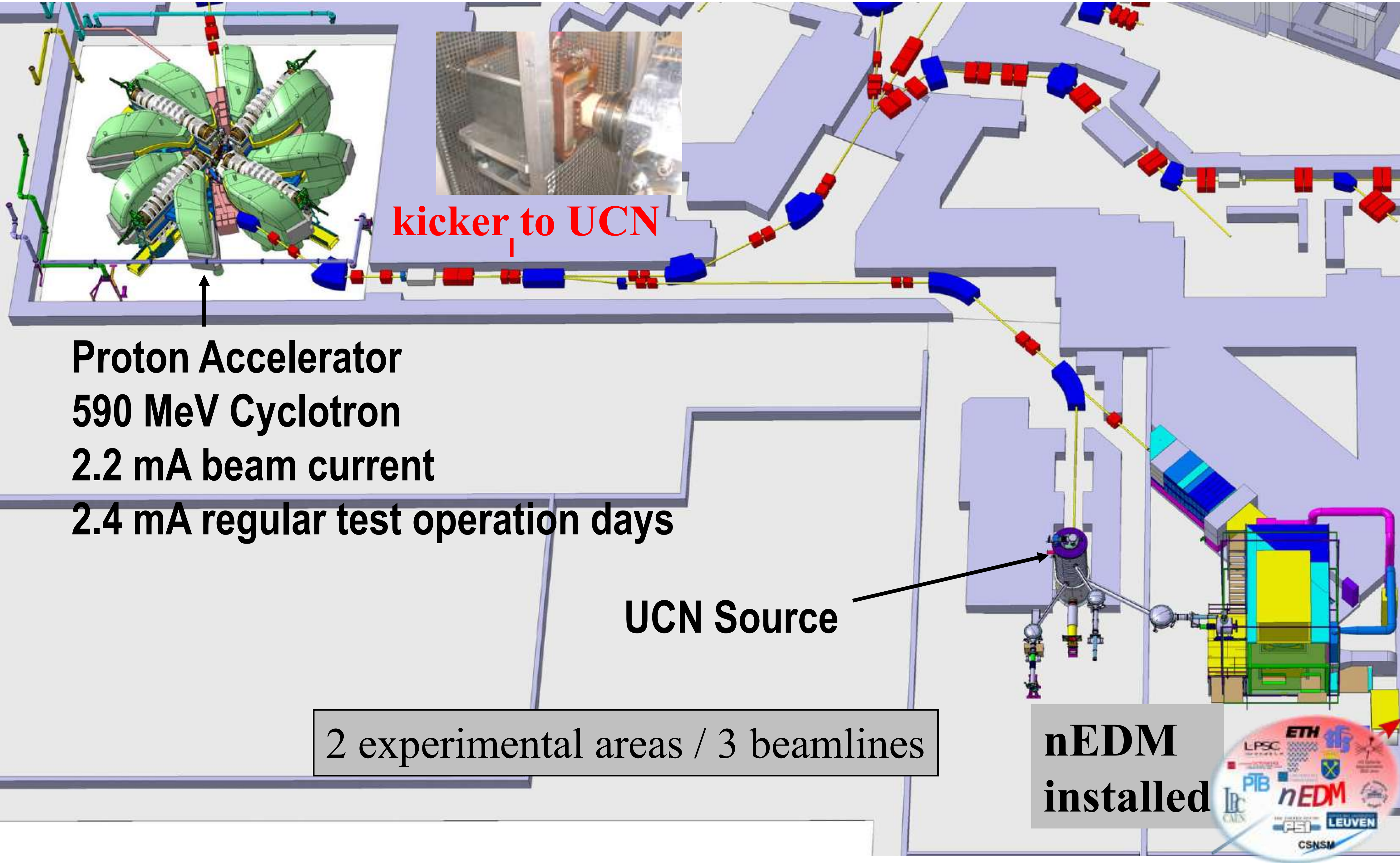
- Characterization measurements of individual sections of the UCN source

The way to PSI - 2600 km



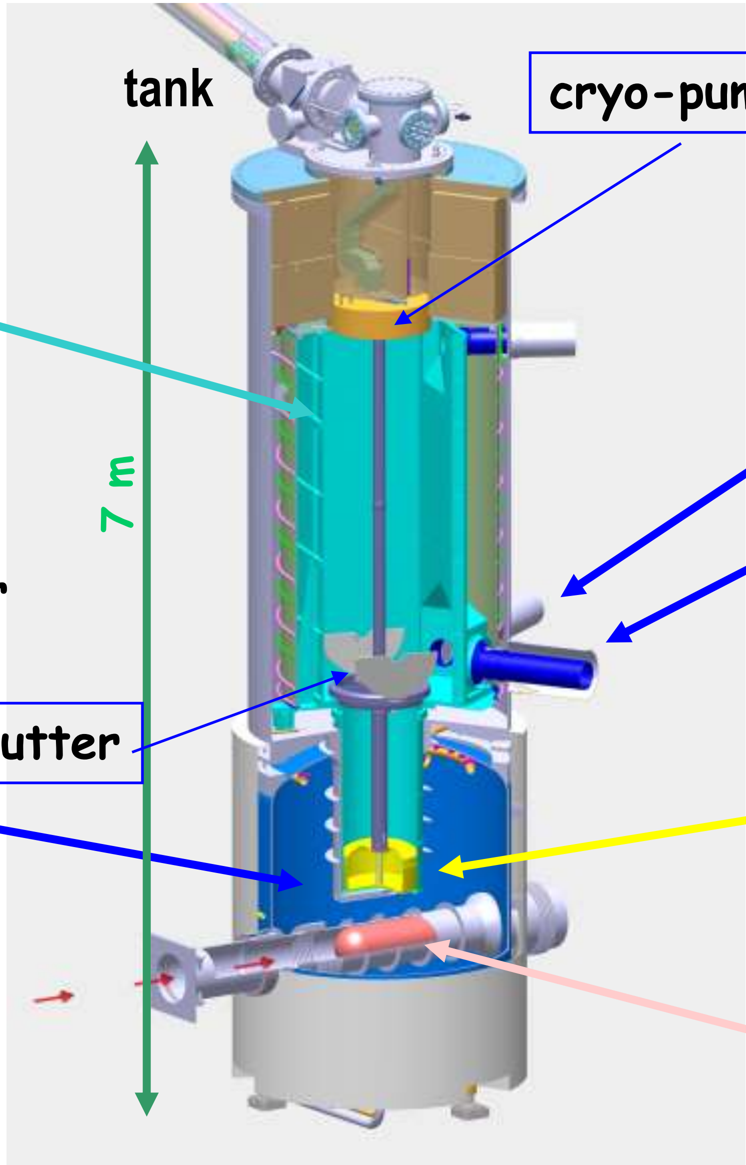

Paul Scherrer Institute
Aare
SwissFEL: γ
600 MeV p cyclotron
p beam current: 2.2 mA
1.3 MW: μ, π
SINQ: n
UCN: n
SLS: γ
Proton cyclotron for
medical application: p

Neutron production via proton spallation on lead



Sketch of the PSI UCN source

DLC coated
UCN storage vessel
height 2.5 m, ~ 2 m^3



cryo-pump

UCN guides towards
experimental areas
8.6m(S) / 6.9m(W)

heavy water moderator
→ thermal neutrons
3.6m^3 D_2O

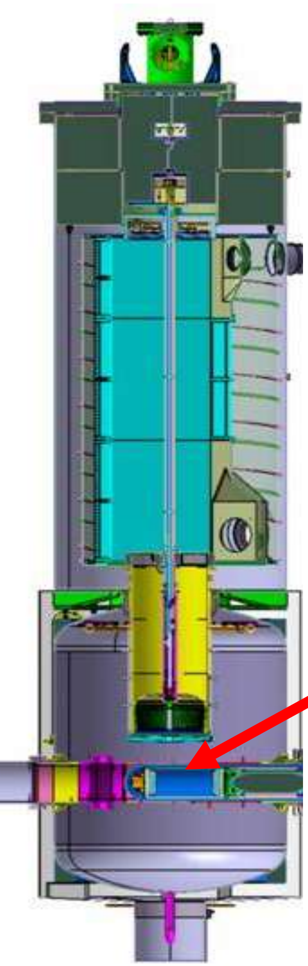
SV-shutter

cold UCN-converter
~30 dm^3 solid D_2 at 5 K

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

spallation target (Pb/Zr)
(~ 8 neutrons/proton)

The lead spallation target



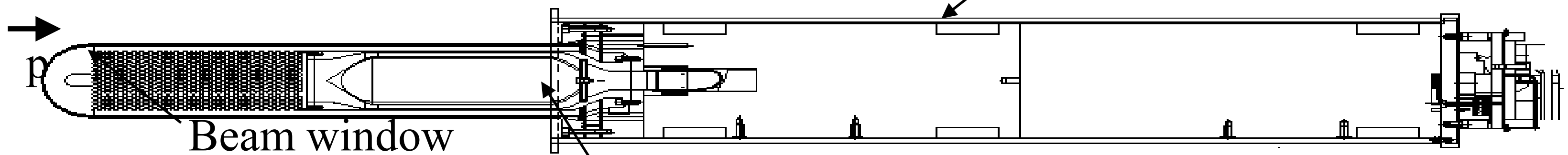
756 Zr/Pb Canneloni

length = 390 cm weigth = 2000 kg cooling = 10 kg D_2O / sec

Target array

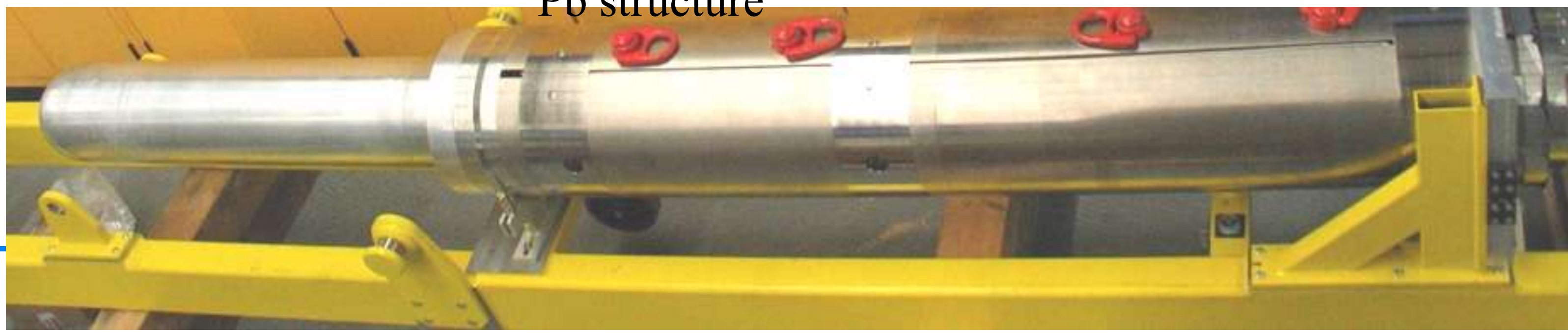
$AlMg_3$ Container

Steel shielding

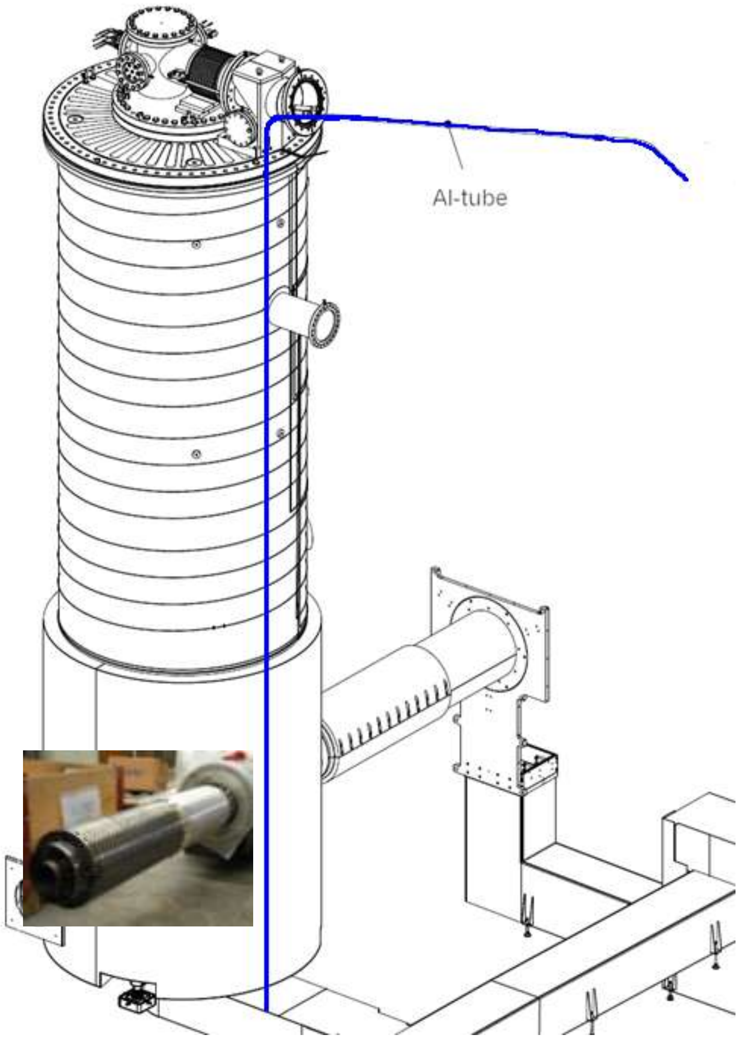


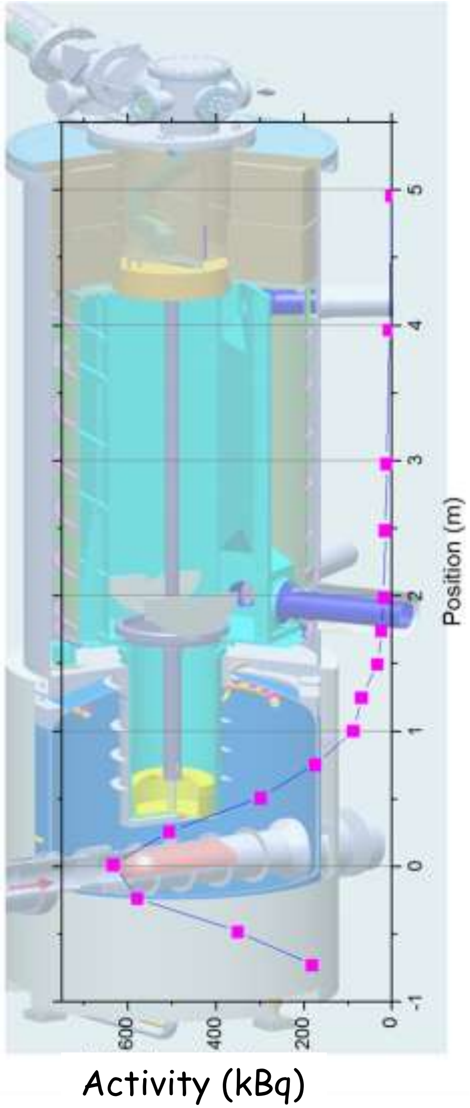
Beam window

Pb structure



Gold foil activation measurement





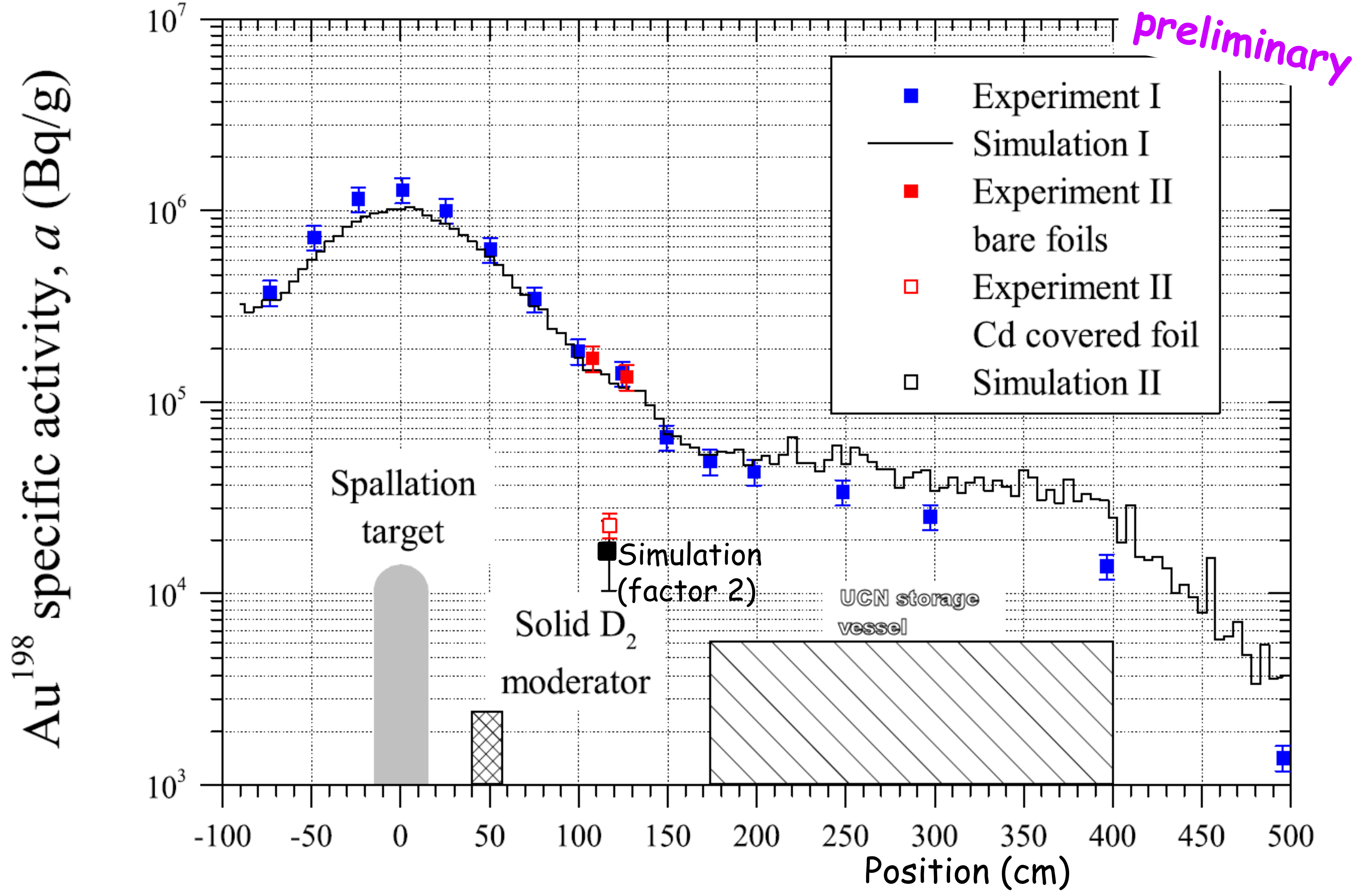
6m
height
profile

calibrated γ-measurement at radio-analytic laboratory of PSI

Comparison of MCNPX simulation and gold measurement

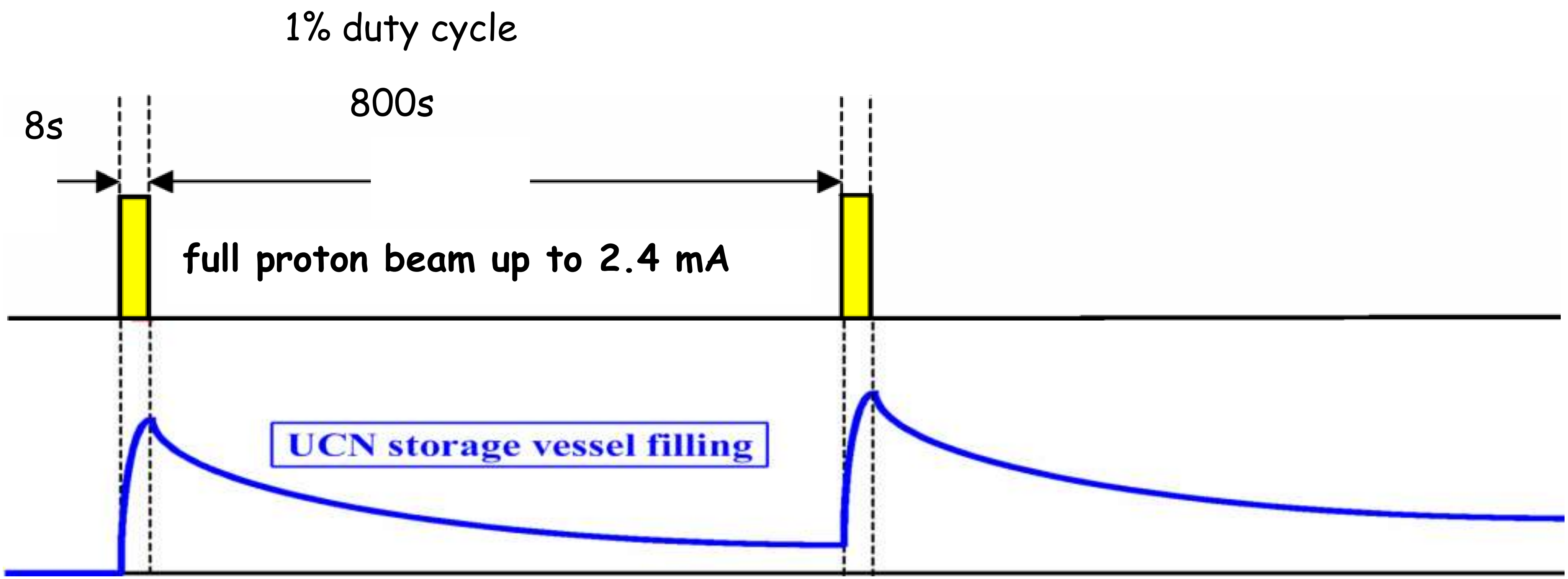
Monte Carlo Simulation and measurement agree at beam height better than 20%

MCNPX calculations



→ ~factor 2 lower cold neutron flux in comparison to early design

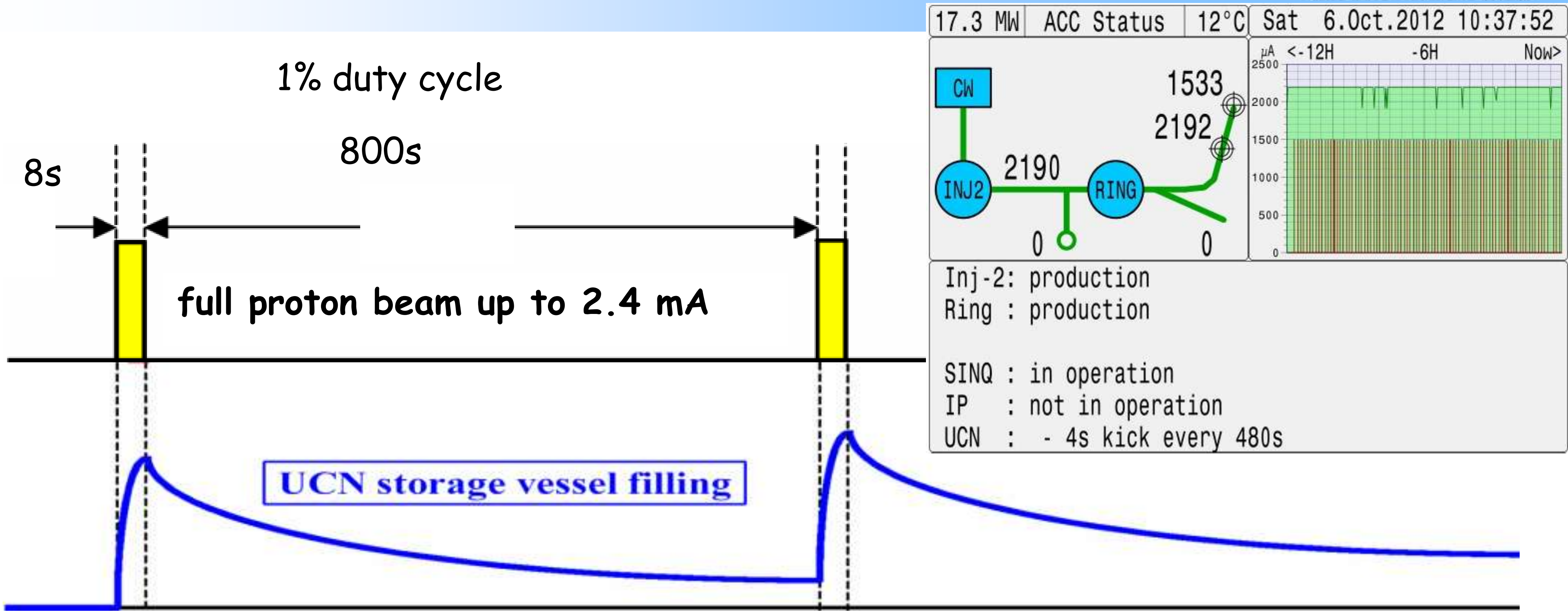
Beam operation scheme



- tested operation of pulses from 7ms, 50ms to 8s
- beam currents from 100 to 2400 μA

- continuous mode operation possible (split beam) with beam current <20 μA

Beam operation scheme

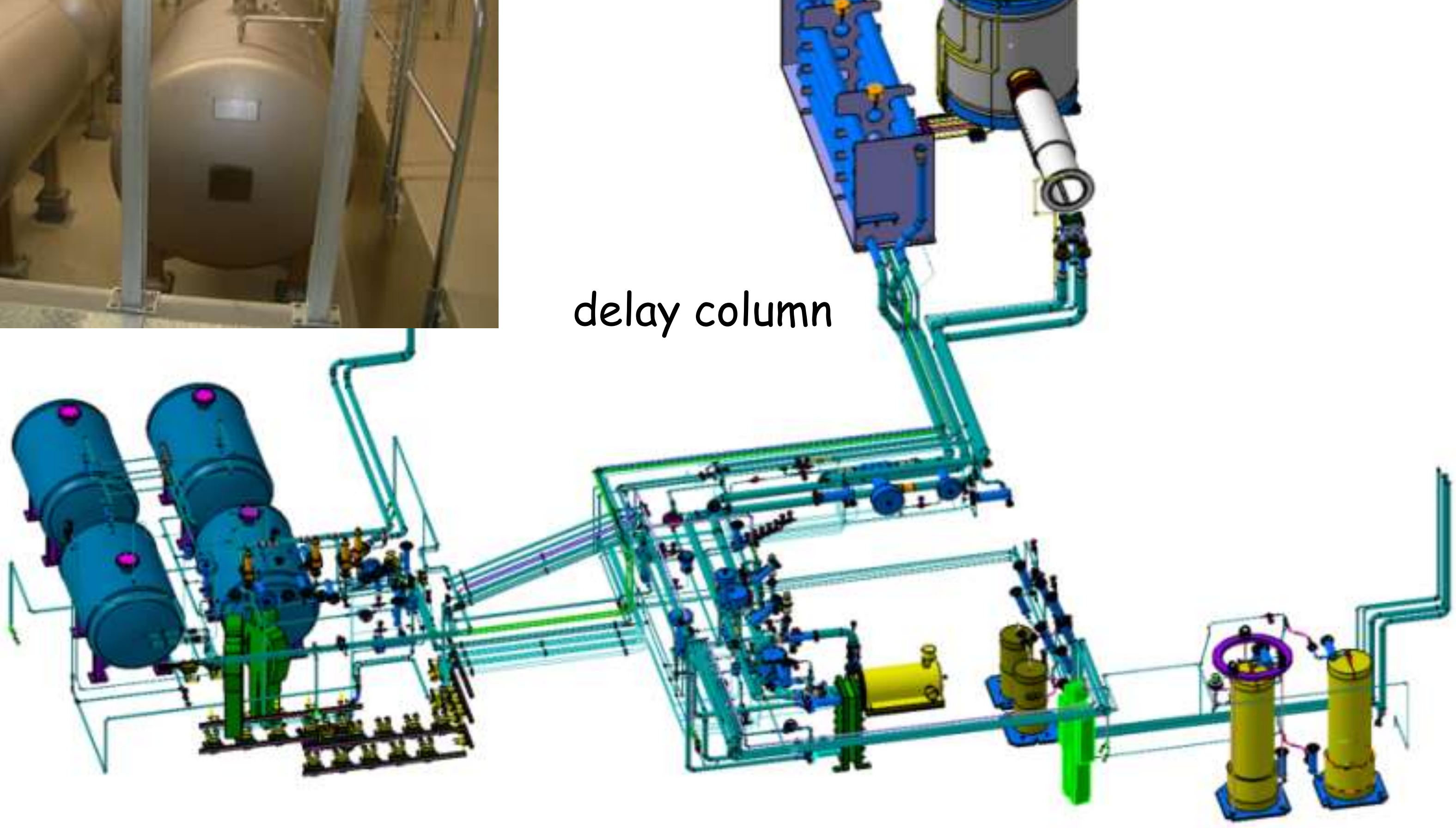


tested operation of pulses from 7ms, 50ms to 8s
and beam currents from 100 to 2400 μA

continuous mode operation possible with beam current <20 μA

Heavy water system for neutron moderation and target cooling

- D_2O purity checked (Jan 2012) – as clean as expected



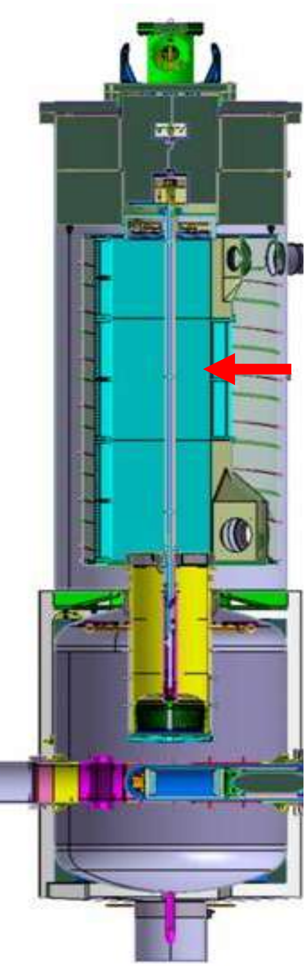
UCN Tank

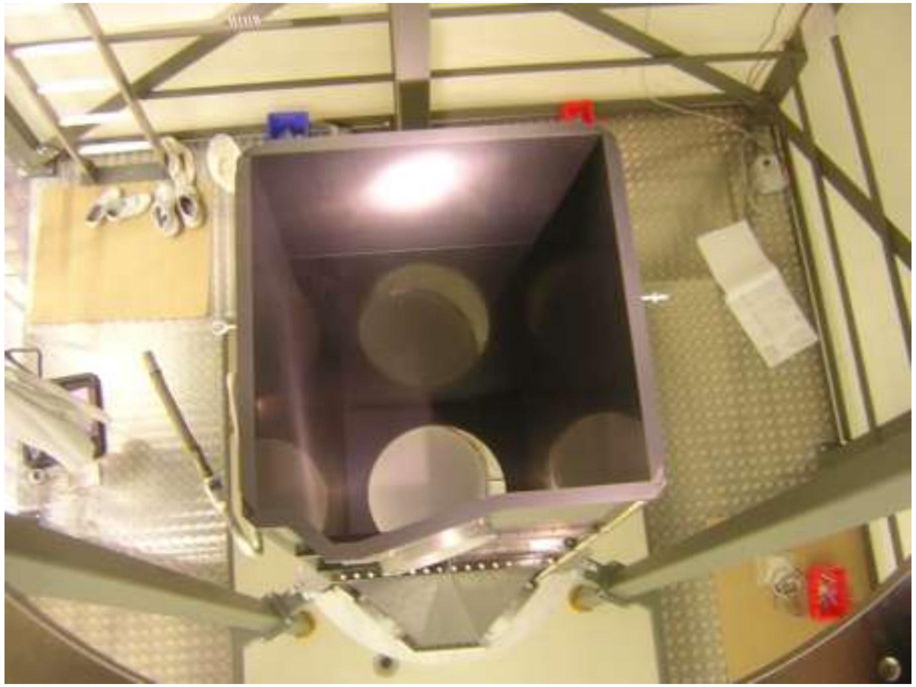
delivery of tank:
Sept. 04, 2008

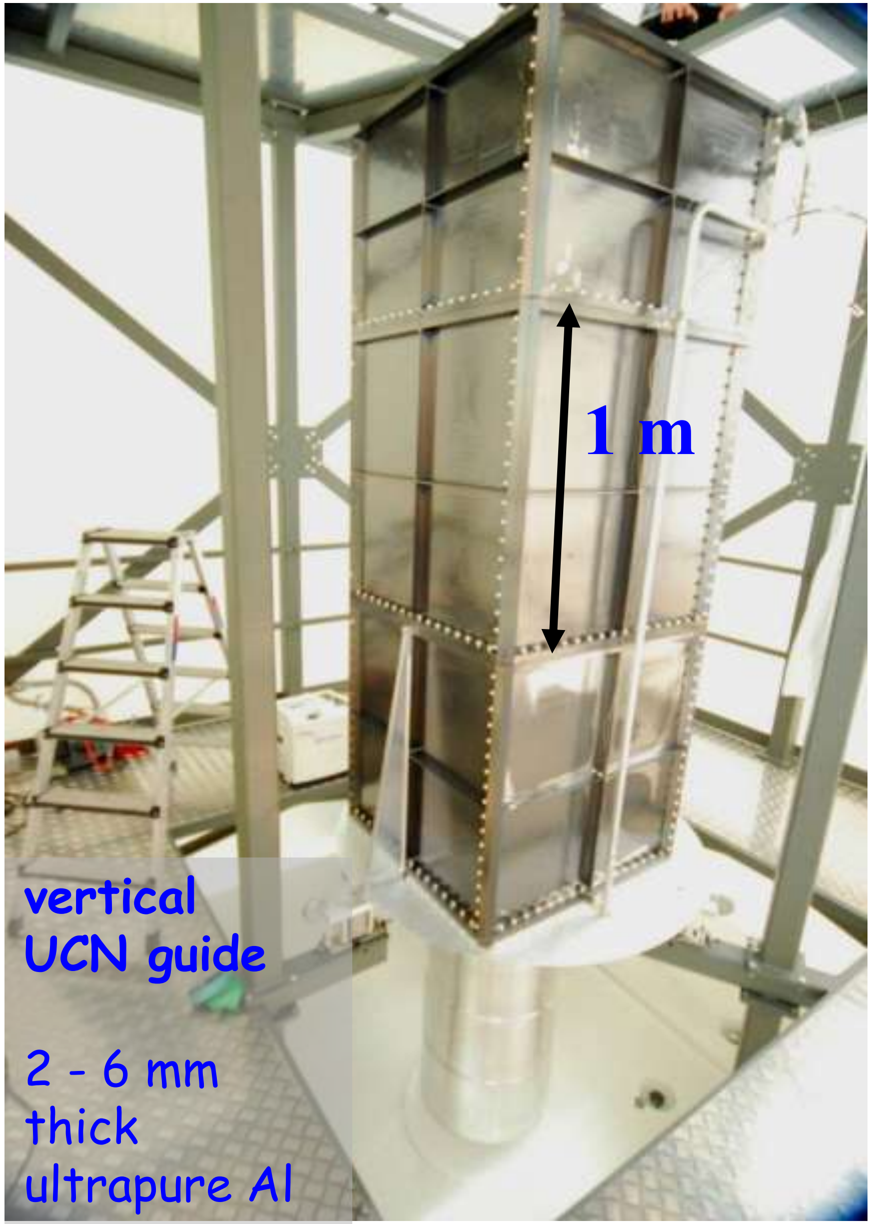
June
2009

December
2009

UCN storage volume

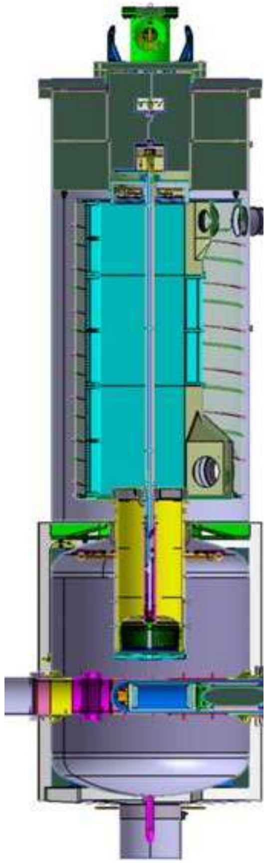






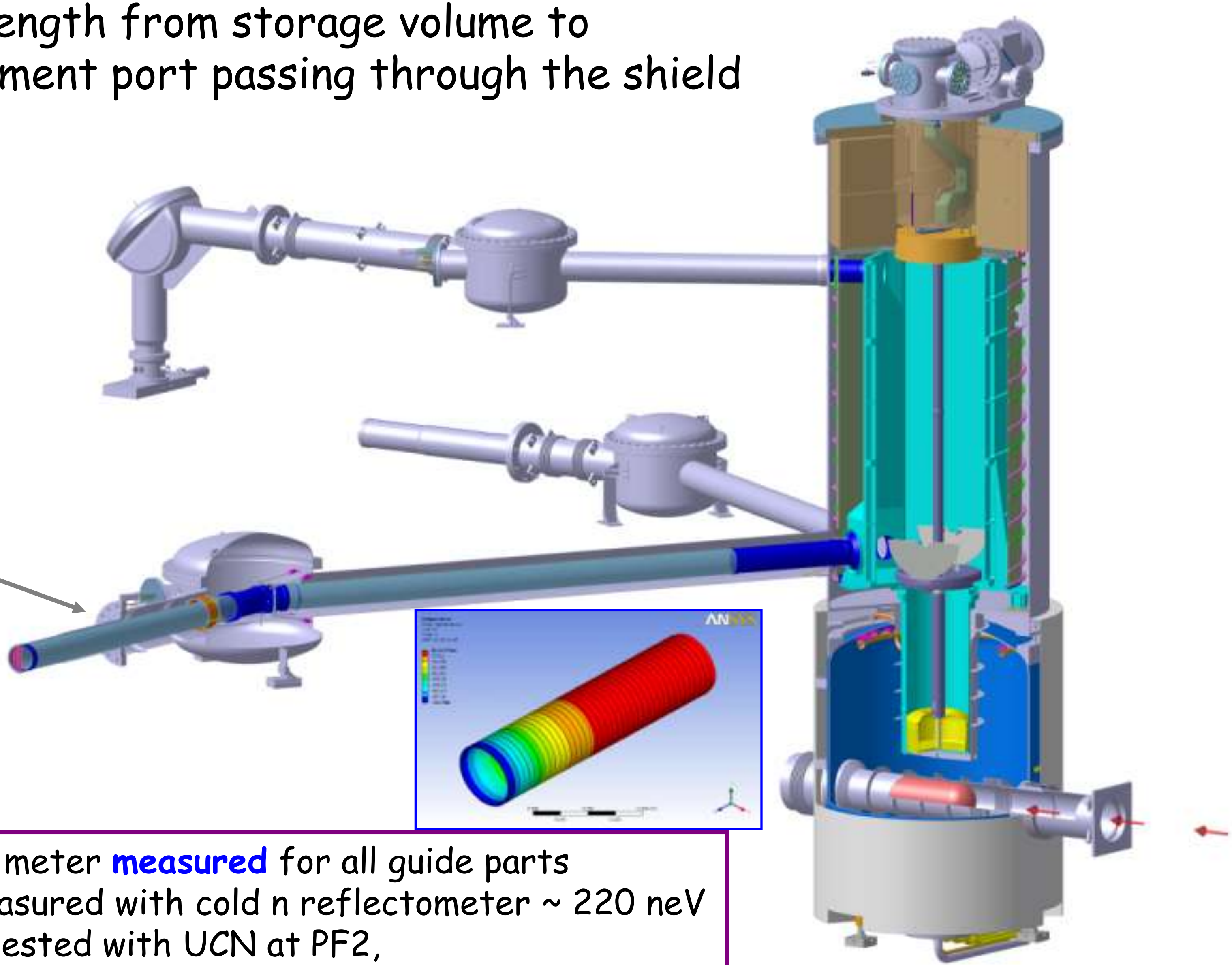
Installation of the storage volume unit and the deuterium unit

fall 2010



Neutron guides pass the biological shield and guide the UCN to the experimental areas

~8 m length from storage volume to experiment port passing through the shield



glass parts
-ID=180mm
-surface roughness better than 1nm
-coated with NiMo

nEDM

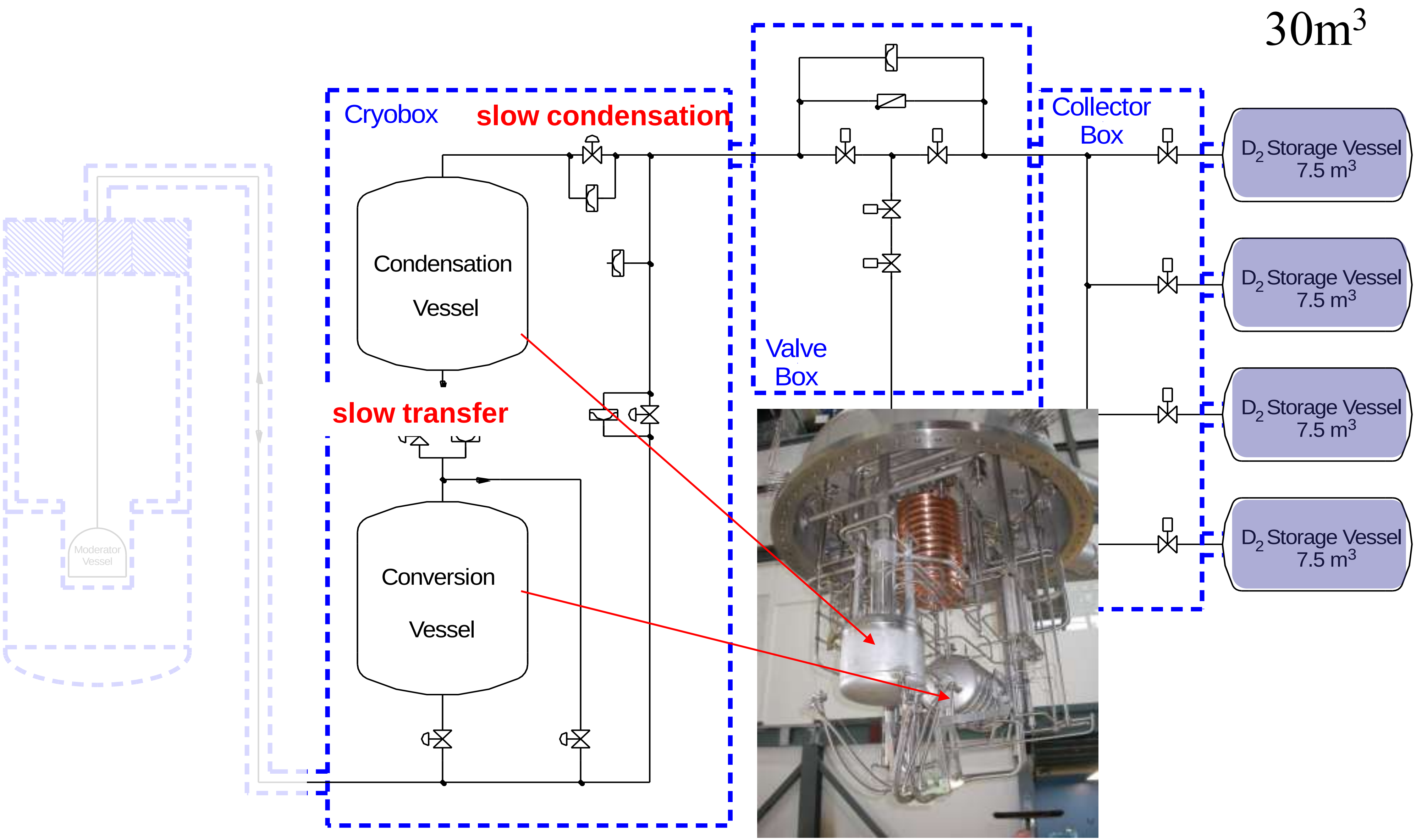
>98% UCN transmission per meter **measured** for all guide parts
- sample for every guide measured with cold n reflectometer ~ 220 neV
- every installed guide was tested with UCN at PF2,

cordial thanks to Peter Geltenbort and Thomas Brenner

Installation of longest UCN guide towards nEDM

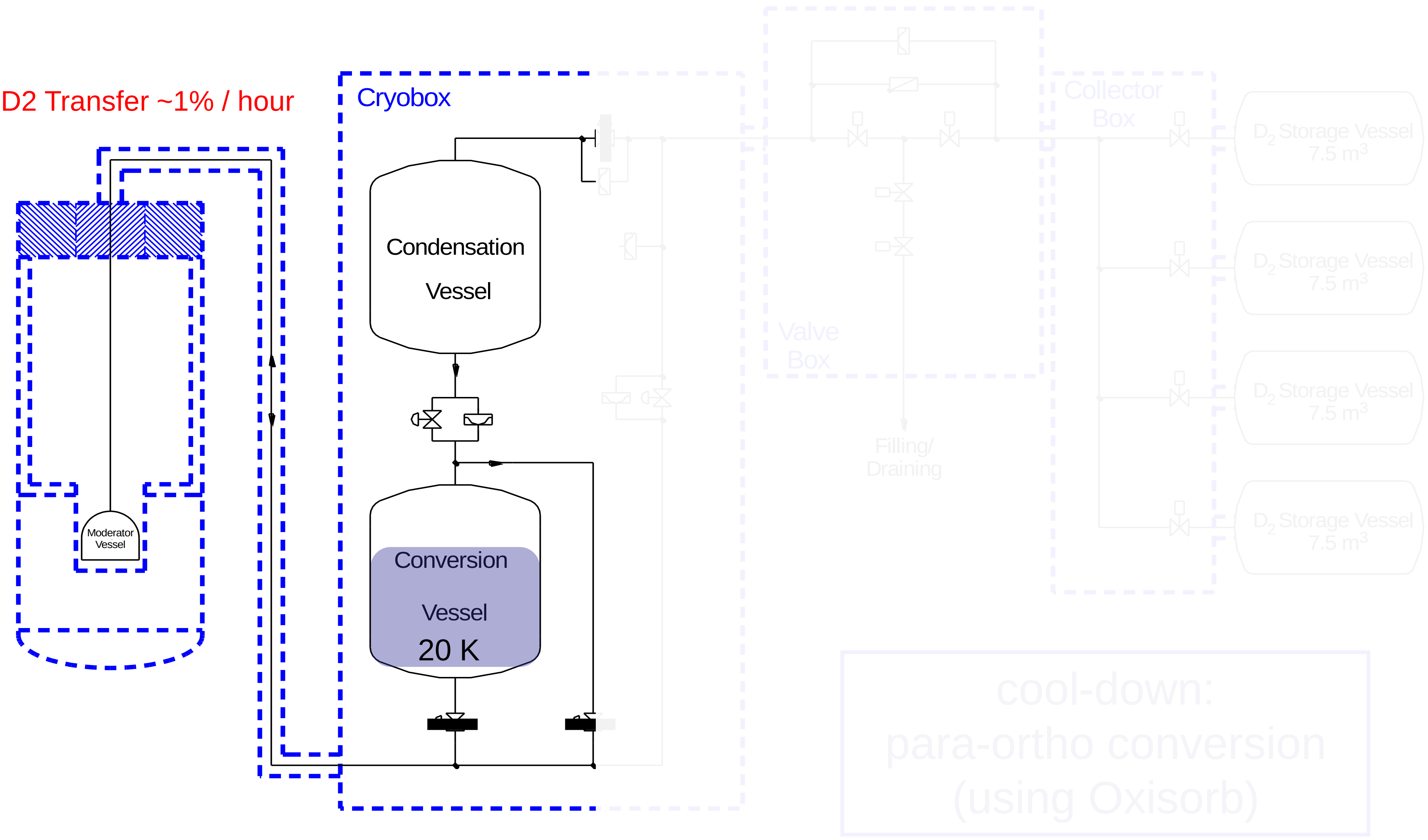
Preparation of the deuterium

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



Preparation of the deuterium

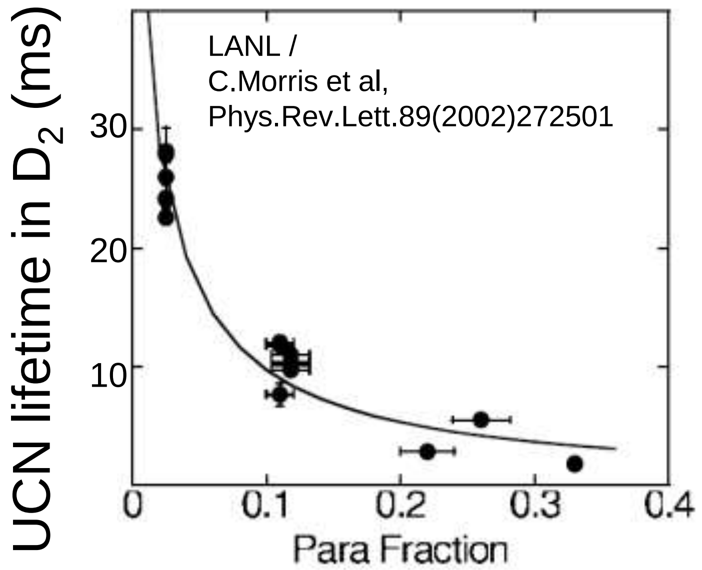
D2 Transfer ~1% / hour



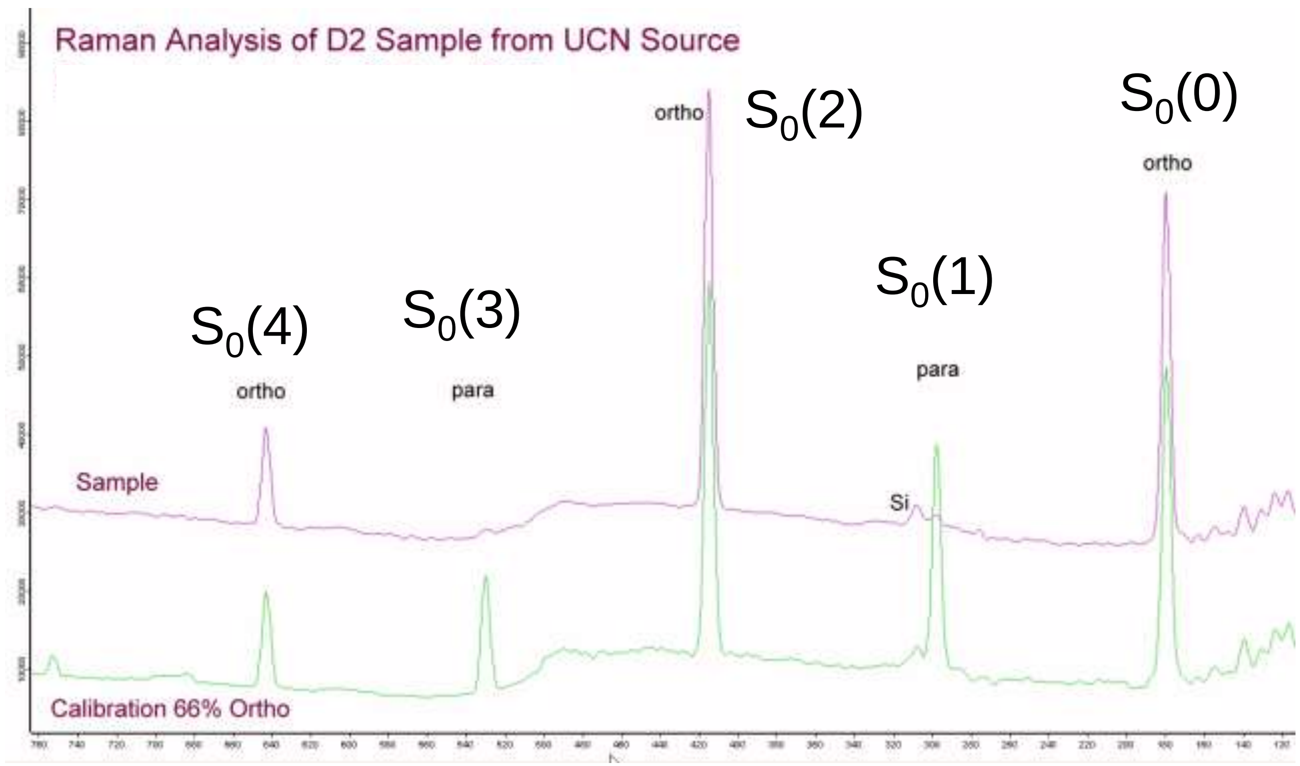
Check conversion of Ortho-to Para-Deuterium

at 98% ortho-D2 τ_{ucn} dominated
by: Nuclear absorption
σ(H) =0.3barn
σ(D)=0.0005barn

ortho/para fraction



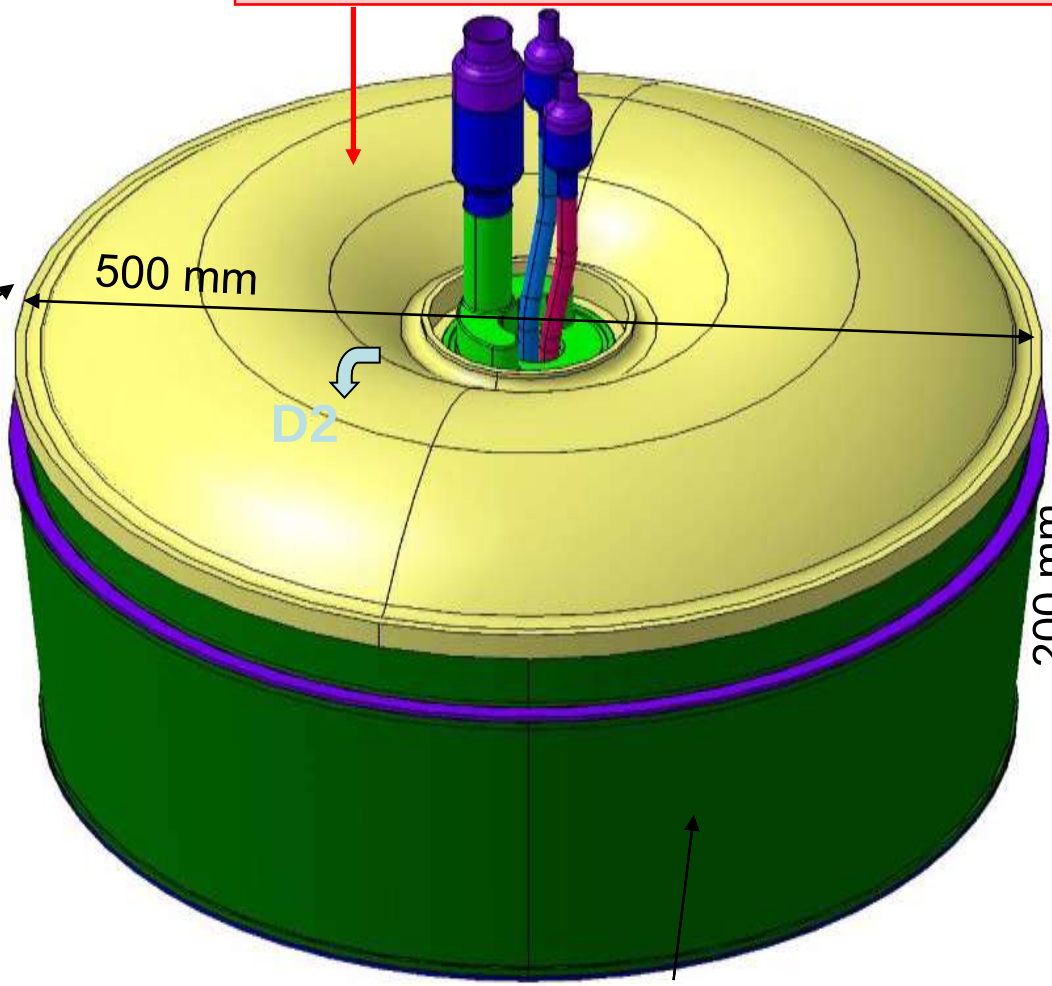
rotational Raman peaks



⇨ 98 ± 2 % ortho-D_2
reconfirmed in several measurements

Solid deuterium at 5K

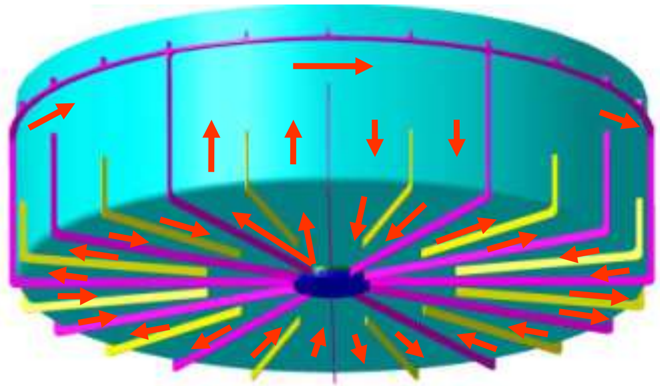
saturated vapor pressure indicates D2 temperature



0.5 mm AlMg3

200 mm

2 × 1.5 mm AlMg4.5Mn



Cooling Agent:
Supercritical Helium

- **solid/liquid/gas level**
- **lid transmission**

Vapor pressure for solidification #12-2

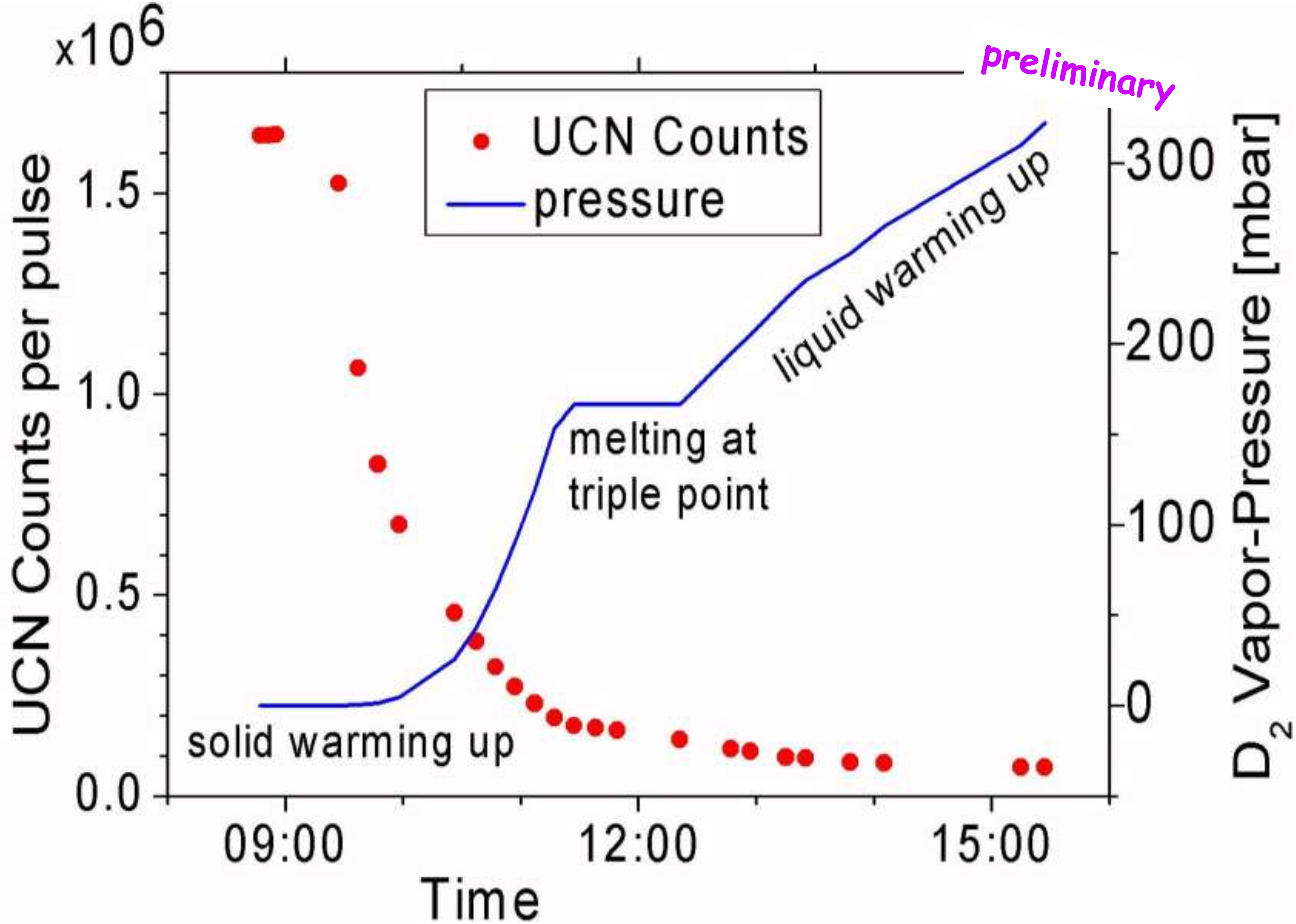
mbar

this example:
7 hours at triple-point,
tried up to 24 hours

Pa

warming up
Triple-Point
all D2 is liquid
start cooling
Triple-Point
solid
full cooling to final pressure

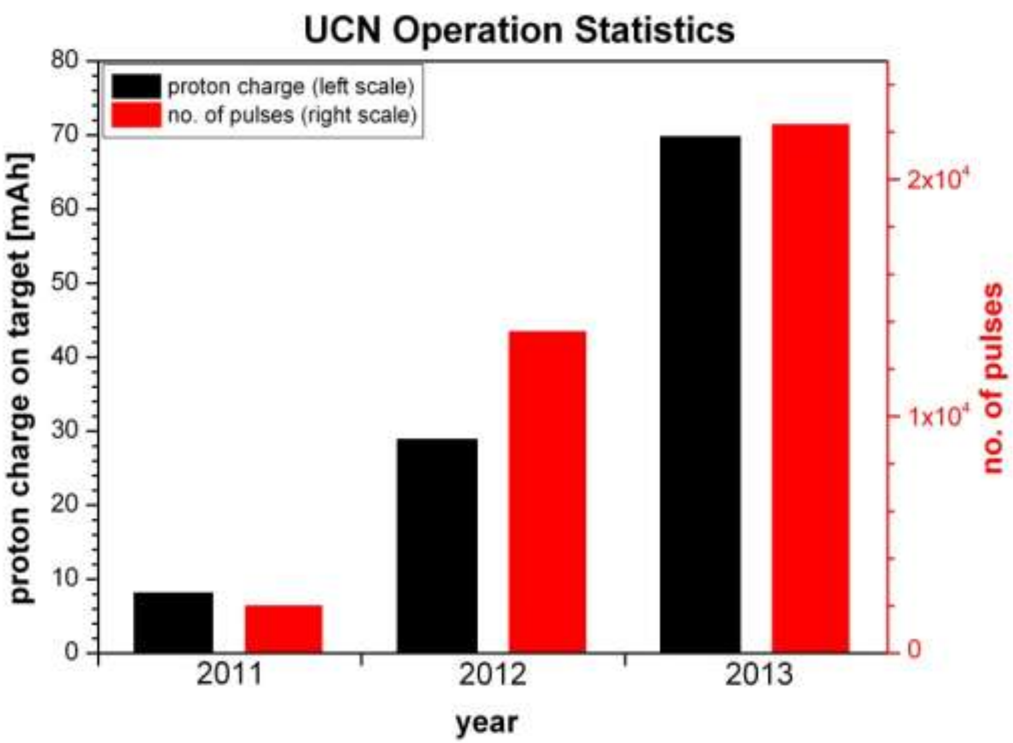
Solid Deuterium Conditioning

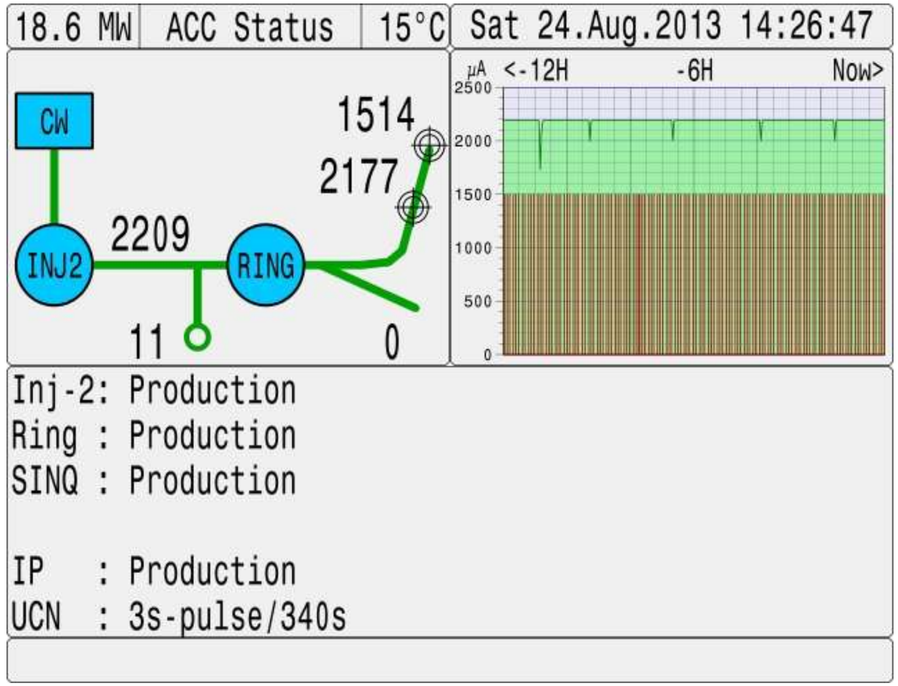


Operations History

- Construction and commissioning of the source was completed in 2010
- Federal authorities` operation approval obtained in June 2011
- Start-up with first beam August 3, 2011 - up to PSI shutdown Dec.2011
- Full operation in 2012 with nEDM commissioning
- Full operation in 2013 with nEDM data taking up to winter shutdown

UCN Operations in 2013



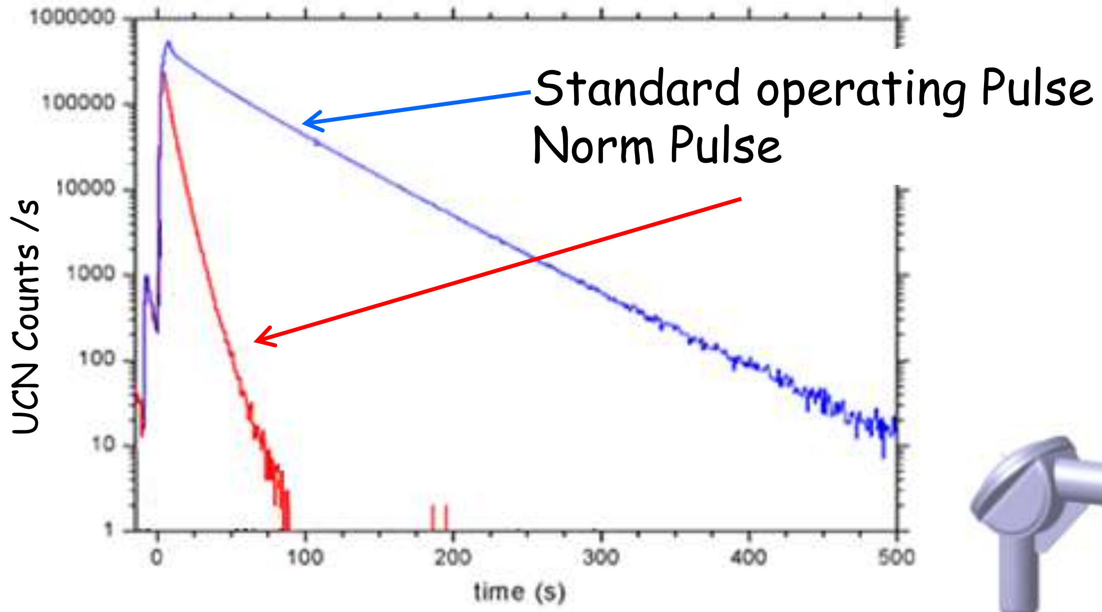


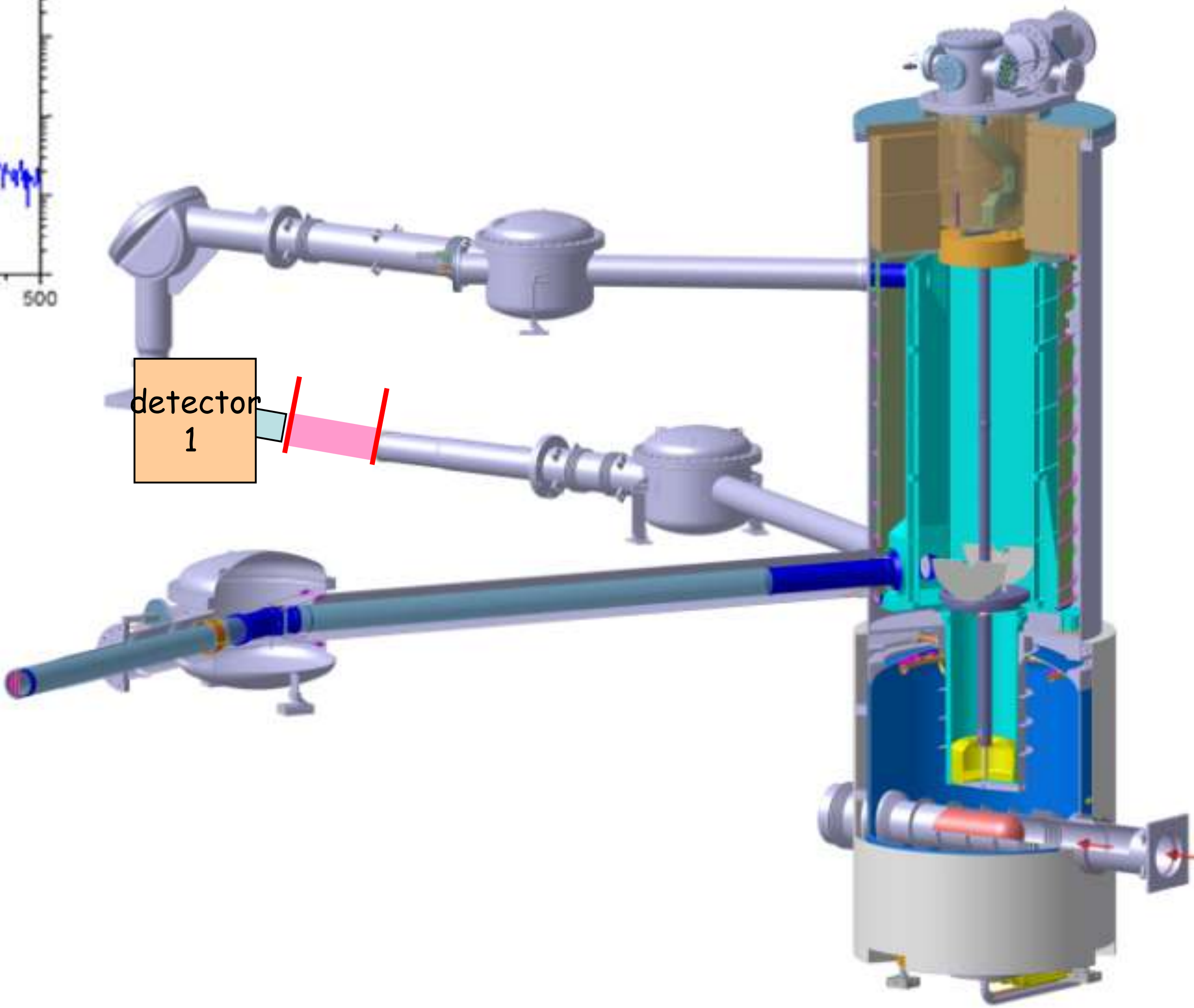
UCN production period May 23 - Dec. 23

69 full days where nEDM could make use of UCN

data taking mode:
- 240 pulses per day
- 7200 pulses per month

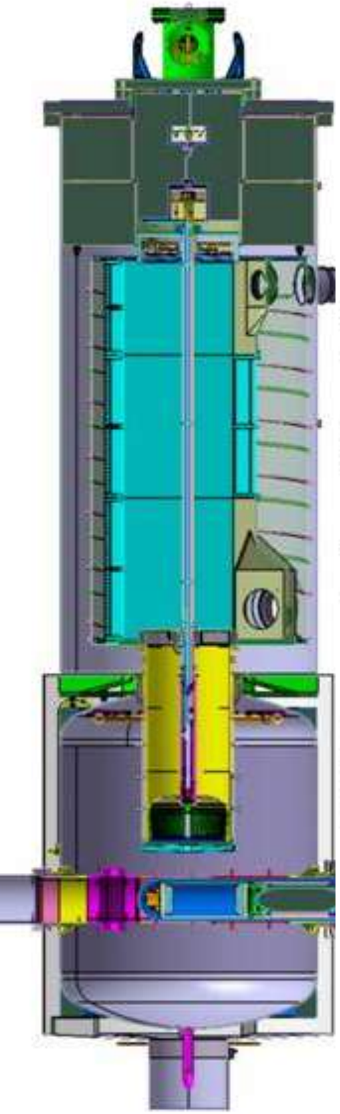
UCN measurement at guide West-1

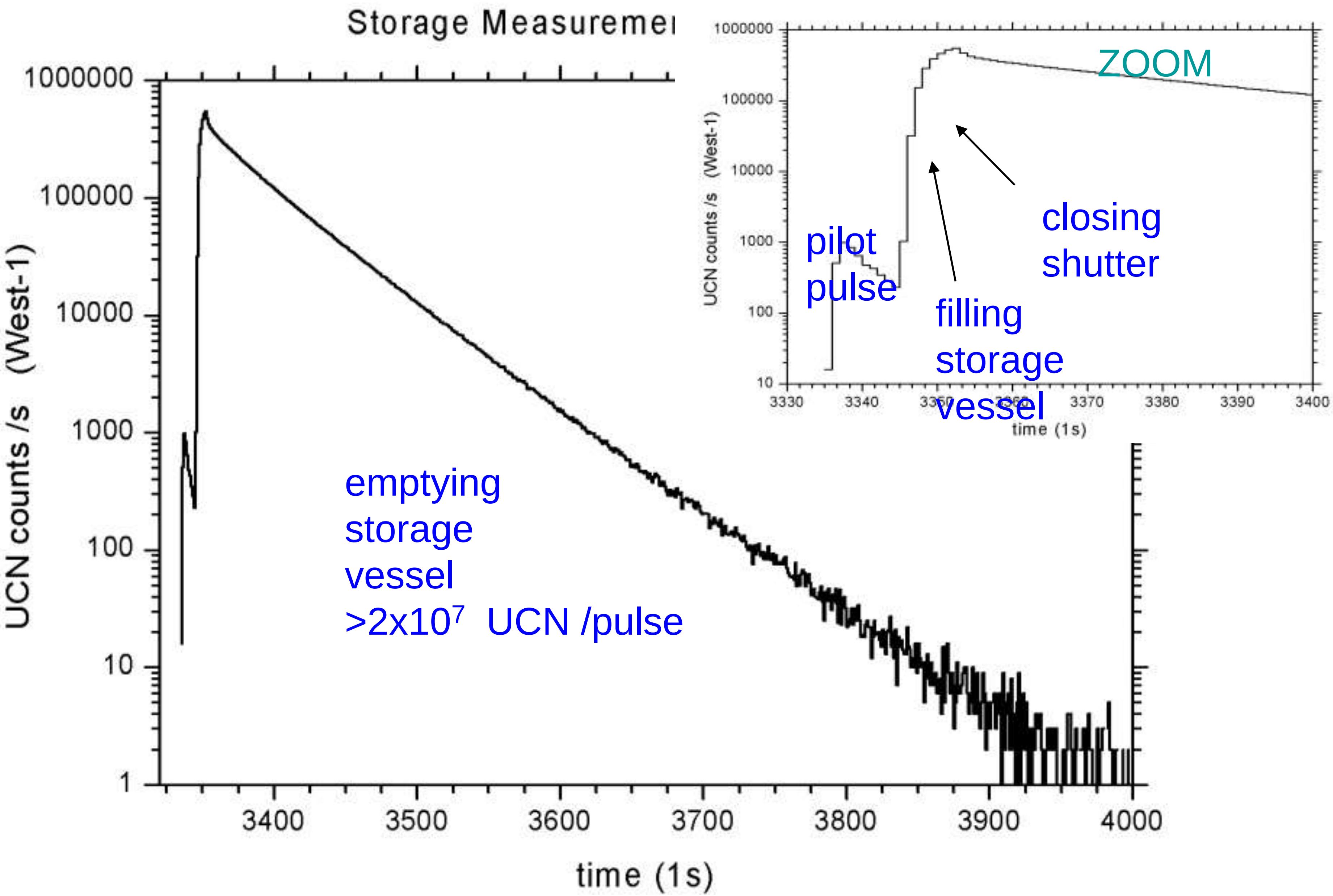




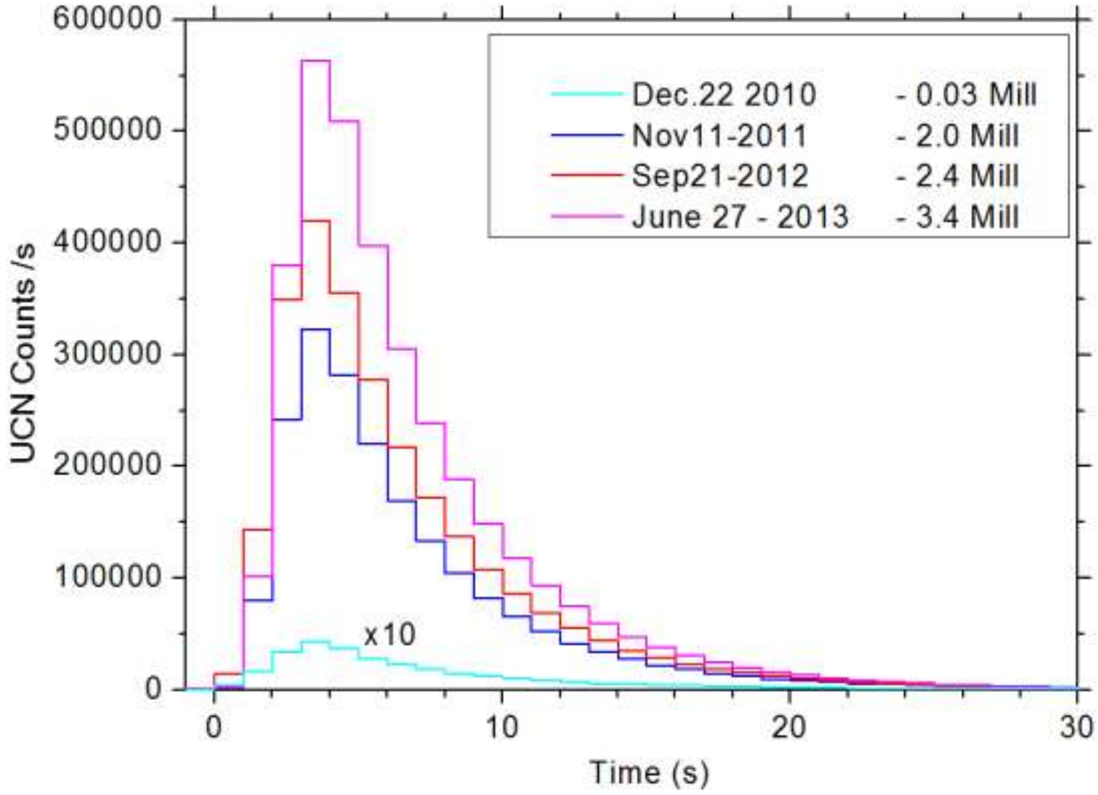
Measurement in area West with detector at beam-port

preliminary





UCN source – status end of 2013



best norm pulse performance in

preliminary

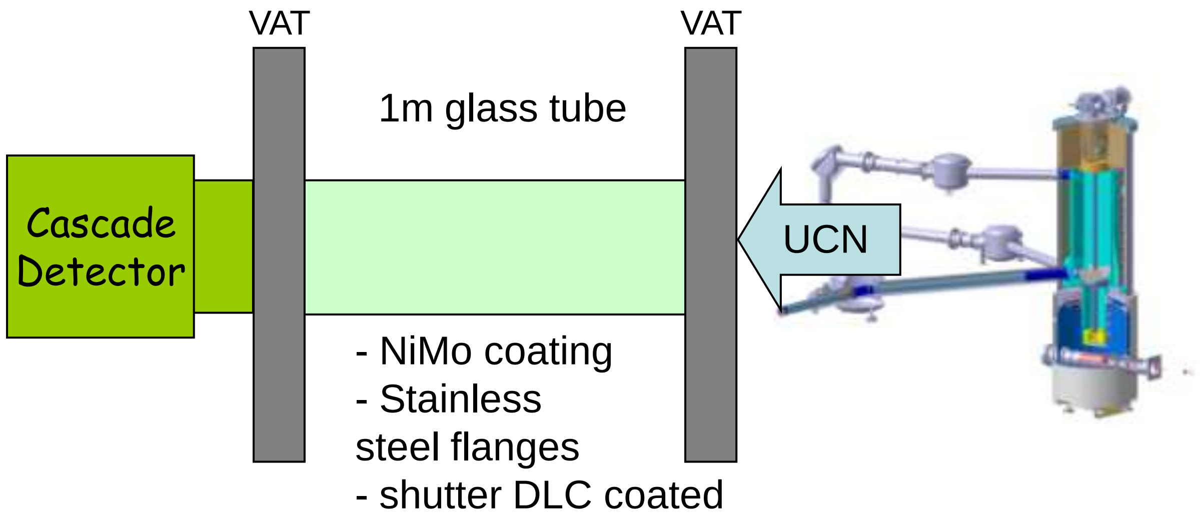
2010: 30'000
2011: 2'020'000 (Nov. 2011)
2012: 2'400'000 (Sept.2012)

2013: 3'450'000 (June 2013) -40% increase

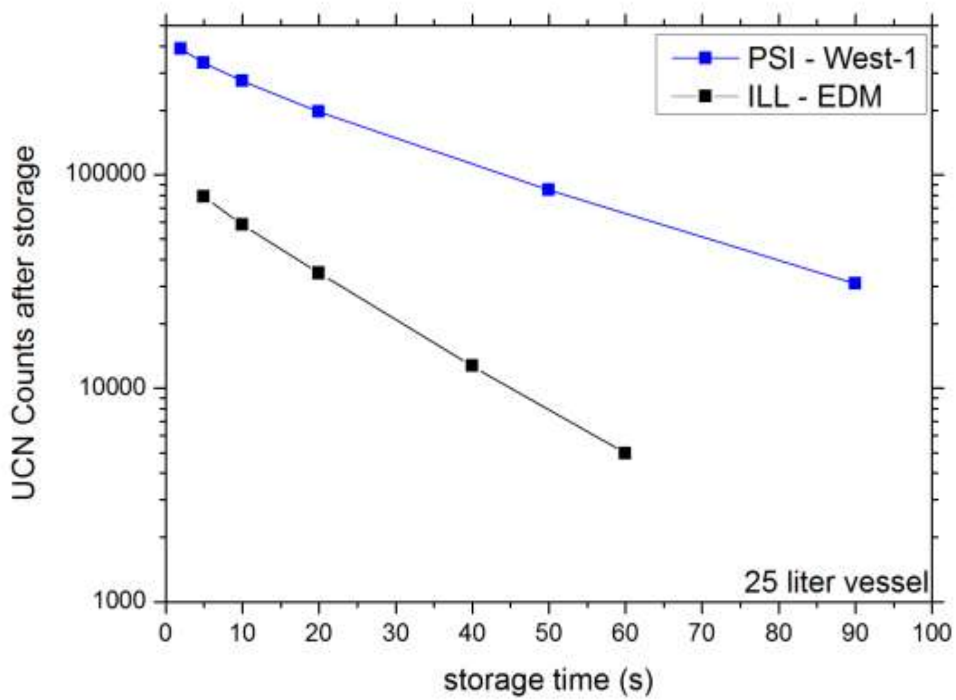
UCN density measurements

UCN density measured in a 25l volume
at experiment site in area West-1:
2013: 535'000 counts after 2s storage
→ ~21 UCN/cm3
→ measured detector foil
transmission = 0.7
→ 30 UCN/cm3

preliminary

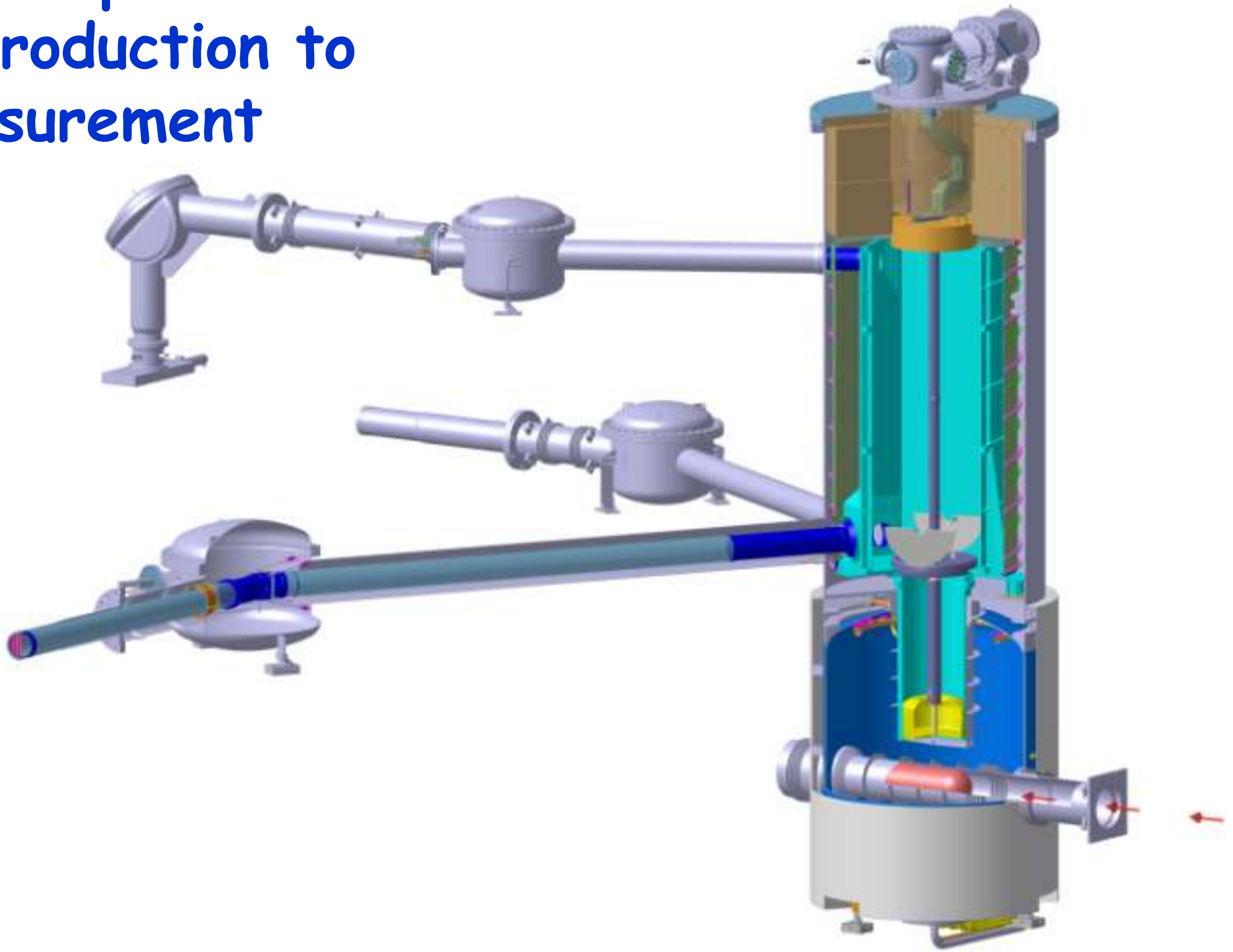


- no corrections yet for
- time = 0 correction
- absolute detection efficiency
- 2.4 mA proton current
- foil correction probably to low
- bad storage vessel -
(large slits during opening and closing)



Strategy to find places of possible losses or defects

check all steps from neutron production to UCN measurement



Cold neutron flux from tritium activity
$n + d \rightarrow t$

IDEA: tritium activity caused by neutron activation is sensitive to neutron velocity via capture cross section dependence 1/velocity

- established thermal neutron flux
- measure tritium activity / water mixed into calibrated scintillation counter for milliBq tritium determination
- works only with water, we can only take a D2 gas sample
- H2, D2, DT via fuel cell → DTO, HTO

D_2

O_2

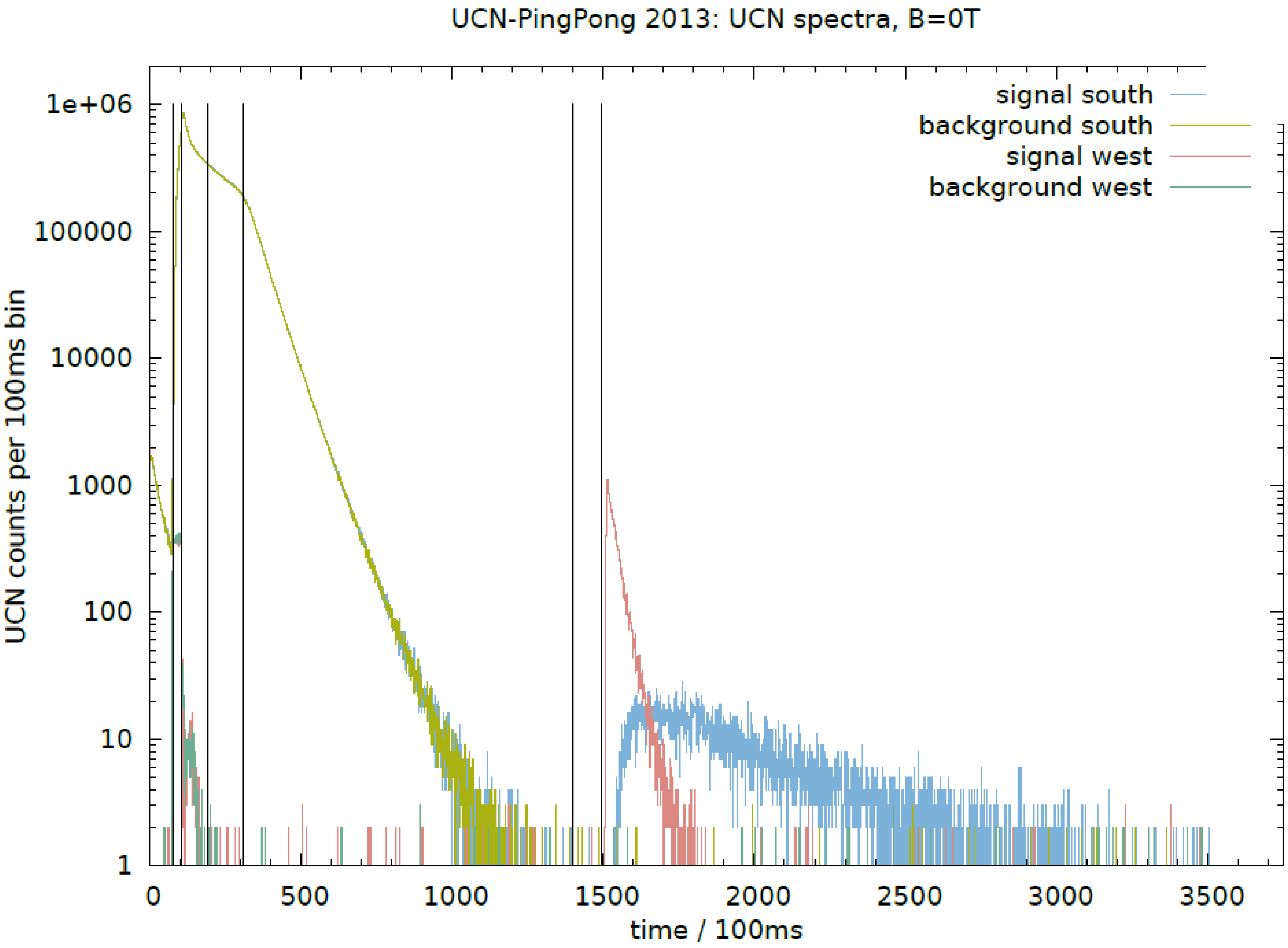
D_2O

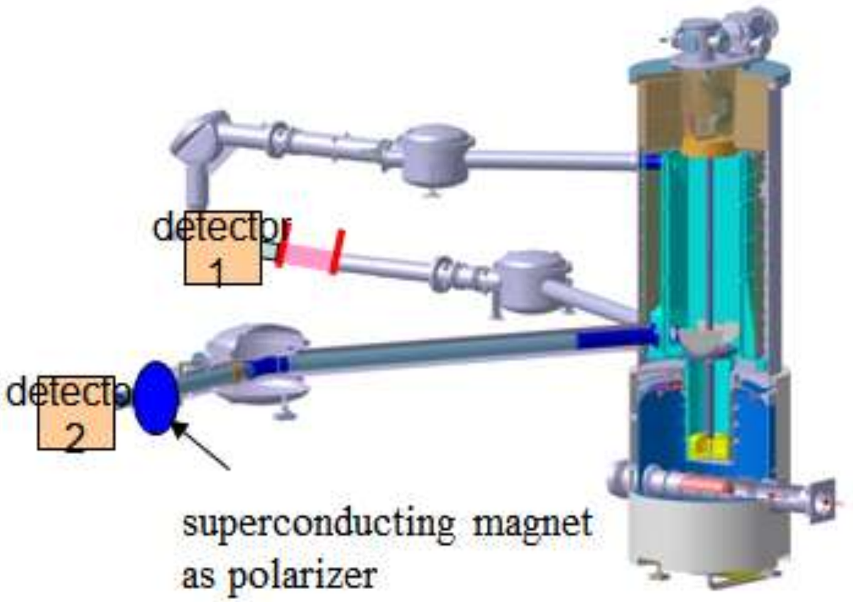
simple calculation for expected activation difference assumes:
homogeneous n-flux: 2×10^{13} n/cm²/s, ρ_{D2}=0.2 g/cm³, $\sigma_{act}=5\times10^{-28}$ cm^{-2}, $\tau_{Tritium}$=17.7a,
proton charge on target= 74.5 C
→ specific activity A = 2×10^{5} Bq/gram (thermal neutrons 2200 m/s)
A = 4.5×10^{5} Bq/gram (cold neutrons 900 m/s)
→ our precision goal 30% to see the difference

- first proof of principle in 2013
- within a factor of 2 - 3 in comparison with simulation

UCN Ping-Pong

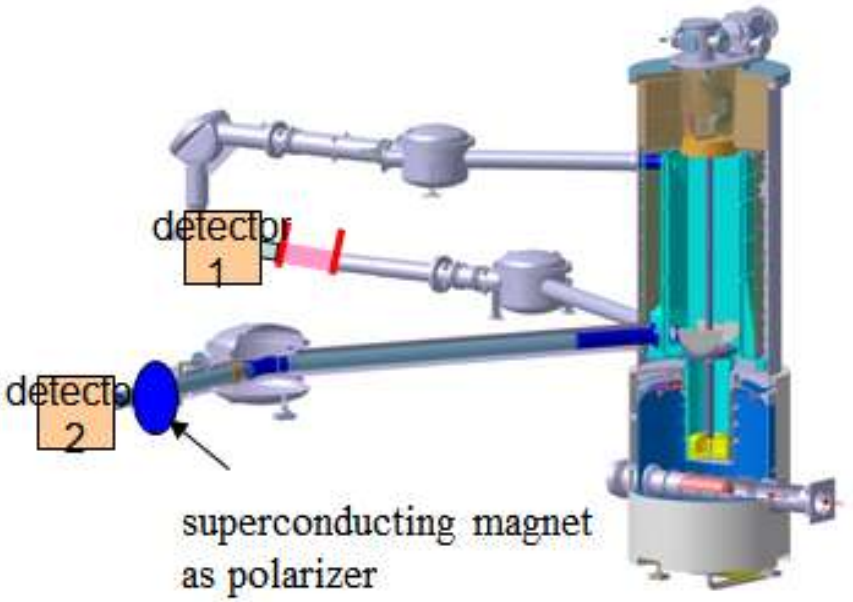
tests UCN optics in guides and storage vessel





- kick beam onto target
- fill small storage vessel in West-1
- open source storage vessel shutter after 10 s
- UCN stored in West-1 for 130s - can be directly measured
- open W1 storage vessel shutter - towards W1 -> measure
- open W1 storage vessel shutter - towards South -> send UCN from West to South
- measure UCN arriving in South

UCN Ping-Pong
comparison 0 and 5 Tesla

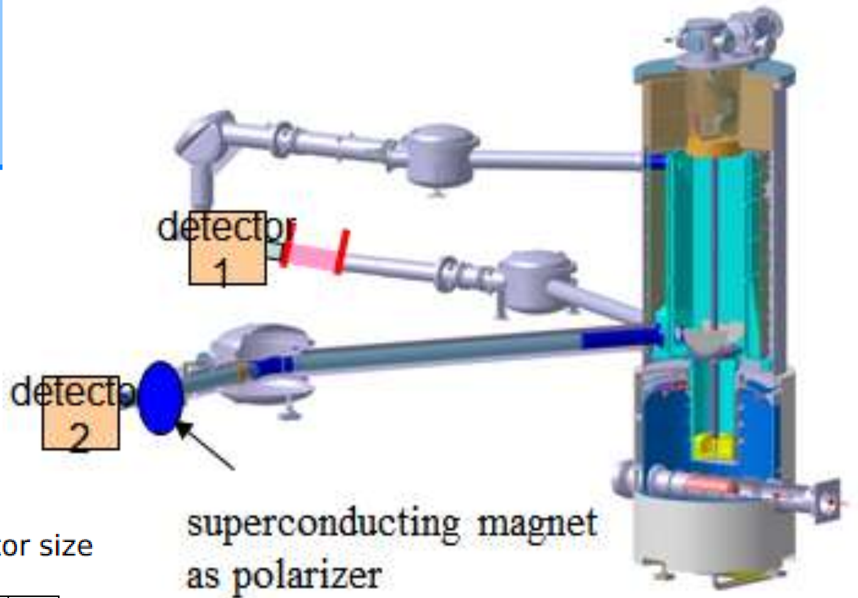


preliminary

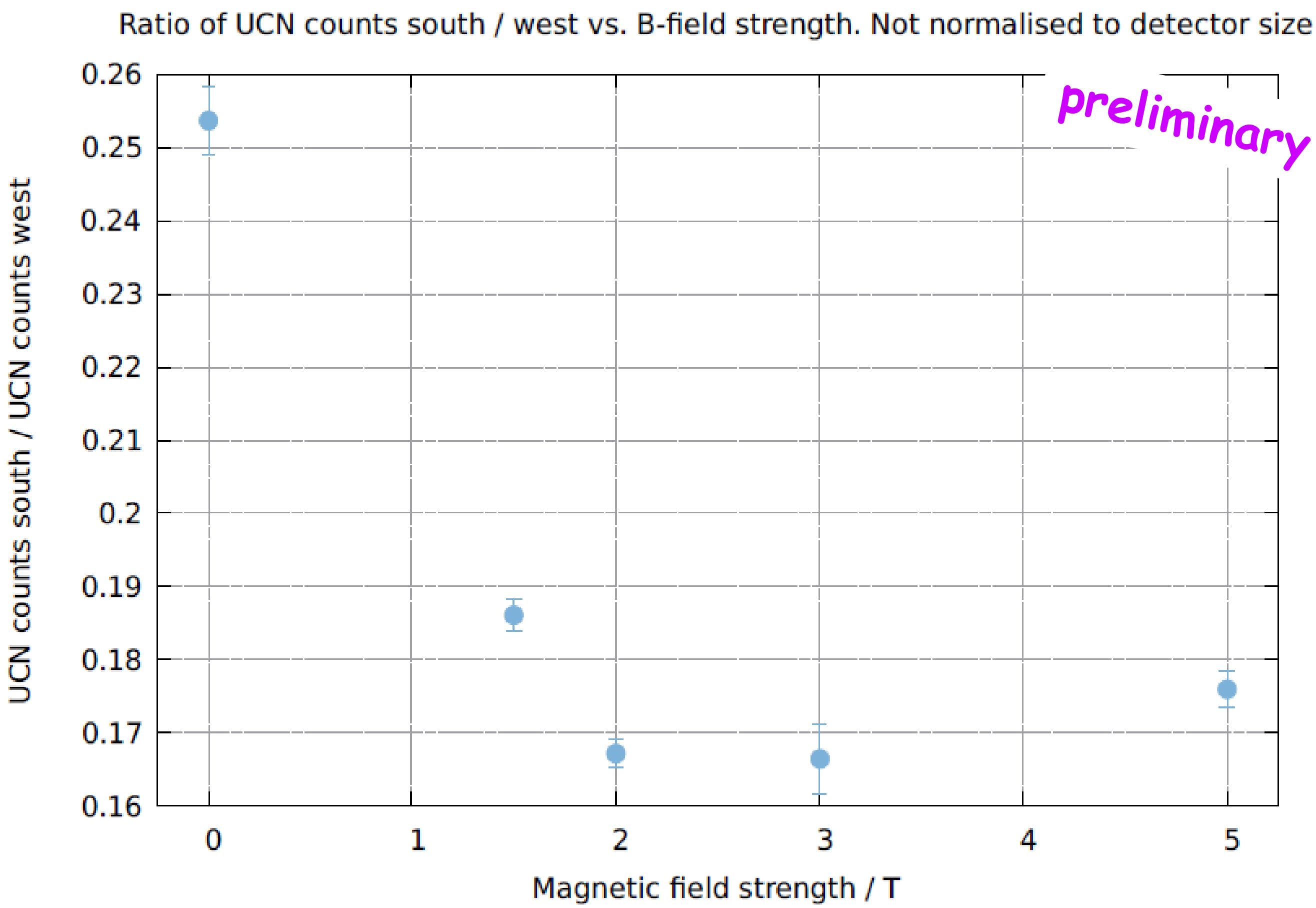
Superconducting magnet status	Measurement 2012	Measurement 2013	Simulation 2012
on - 5 T	0.073±0.010	0.070±0.001	0.083±0.008
off - 0 T	0.130±0.023	0.101±0.002	0.095±0.008

UCN arrival probability in detector at South beam port

UCN Ping-Pong comparison 0 to 5 Tesla

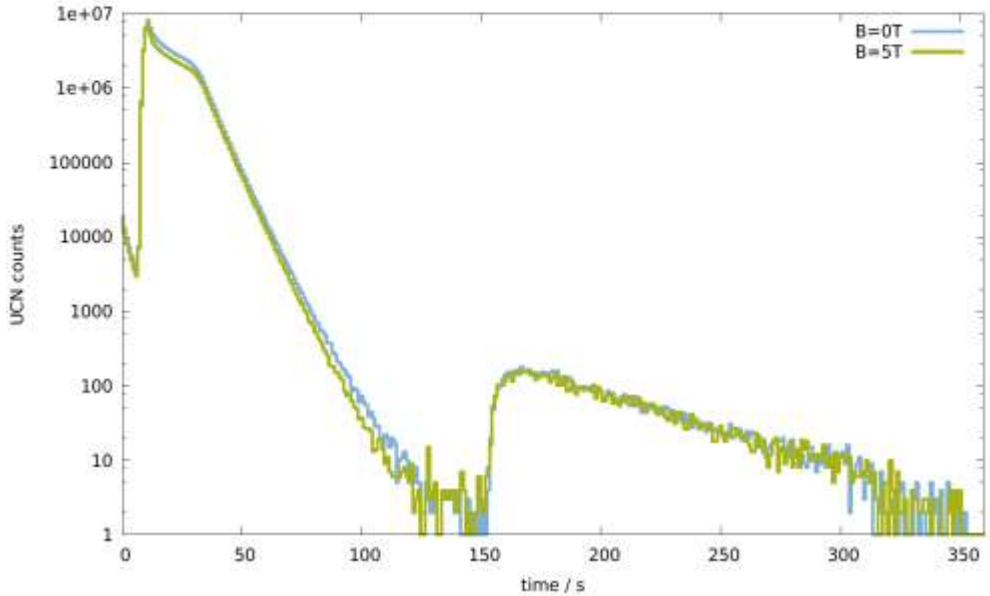


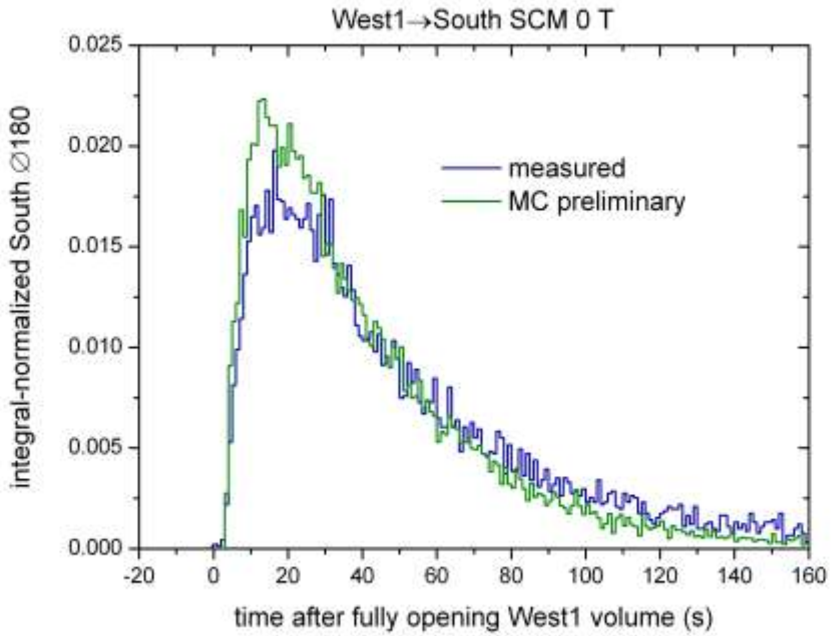
little count rate difference observed between 5 T and 2 T setting
→ En < 180 neV



Compare to UCN energy spectrum in simulation

Ping Pong - UCN arrival times: simulation matches measurement





full simulation reproduces measurements well

➔ no 'big' unknowns in storage vessel or guides

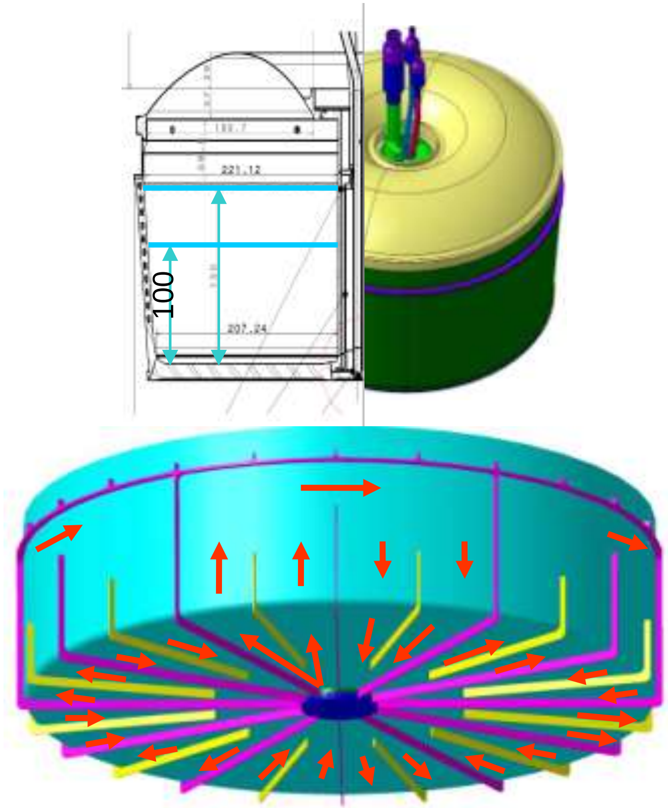
➔ UCN loss (except windows) occurs below shutter

A 'calibrated' source of UCN
Production in solid thin-film D2

D2 fills with gas → exact D2 mass known

→ freeze to make a solid thin-film D2 source

3 & 6 gram targets -
→ thickness 10 - 50 micron



→ no UCN losses occurring within the solid D2 (lifetime is long enough that UCN exit also after multiple scattering)

- established thermal flux
- (soon established) cold flux
- established UCN production cross-section from Golub/Boenig 1983, Yu/Malik/Golub 1985 Atchison et al, PRC71, 2005 Atchison et al, PRL99, 2007

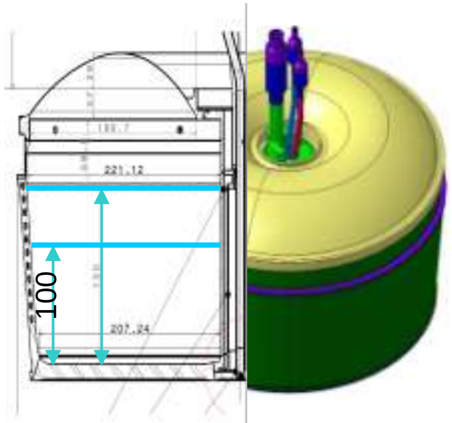
- established UCN transport to detector above the SV shutter (Ping Pong)

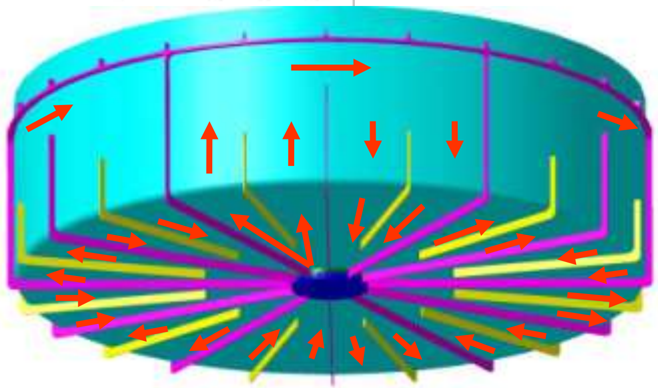
→ check UCN extraction and transport below SV shutter via thin film measurement

A 'calibrated' source of UCN Production in solid thin-film D2

preliminary

mass (g)	Measurement UCN counts	Simulation UCN Counts
5.77±0.2	28'100±1300	30'000
2.82±0.2	16'070±500	15'000





We plan for several checks in 2014:

- reproducibility
- different thicknesses of D2
- temperature dependence of UCN rate in 1 thin D2 layer

Summary

- The UCN source at PSI is commissioned and working well.

- The UCN source has regular beam operation to supply UCN to the nEDM apparatus and other users.

- UCN density improved by factor of about 100 since start-up. Further optimization of all source parameters is under way.

Thanks for your attention