Production of ultracold neutrons

The Mini-D_2 UCN-source

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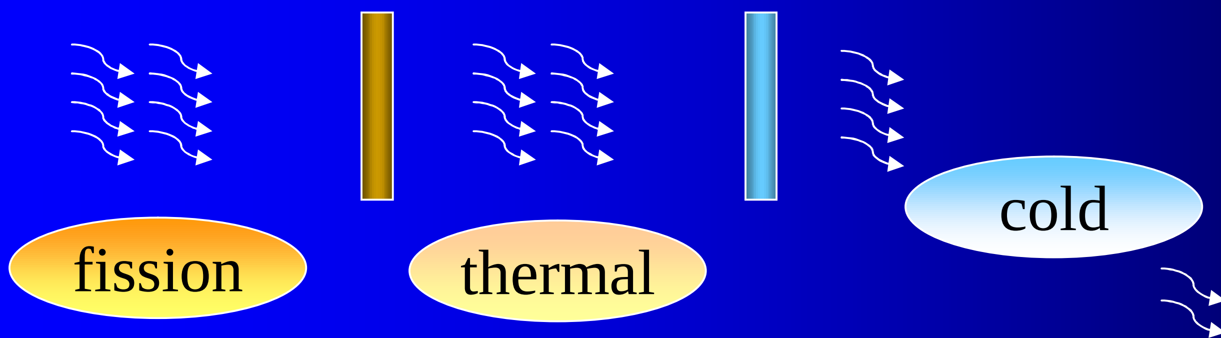
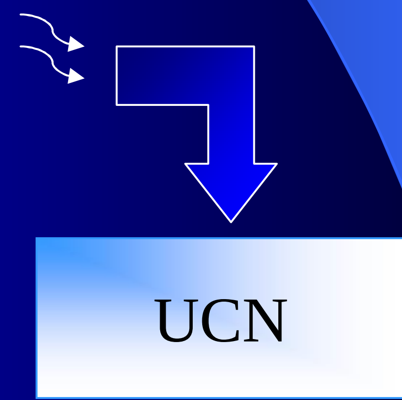
MLL-Kolloquium (10 Feb. 2005)

- Basic ideas of Mini-D_2
- Deuterium as UCN converter
- The TRIGA-Mainz test setup
- Status of the project
- First results of experiments

How are UCN produced?

By downscattering of higher-energy neutrons

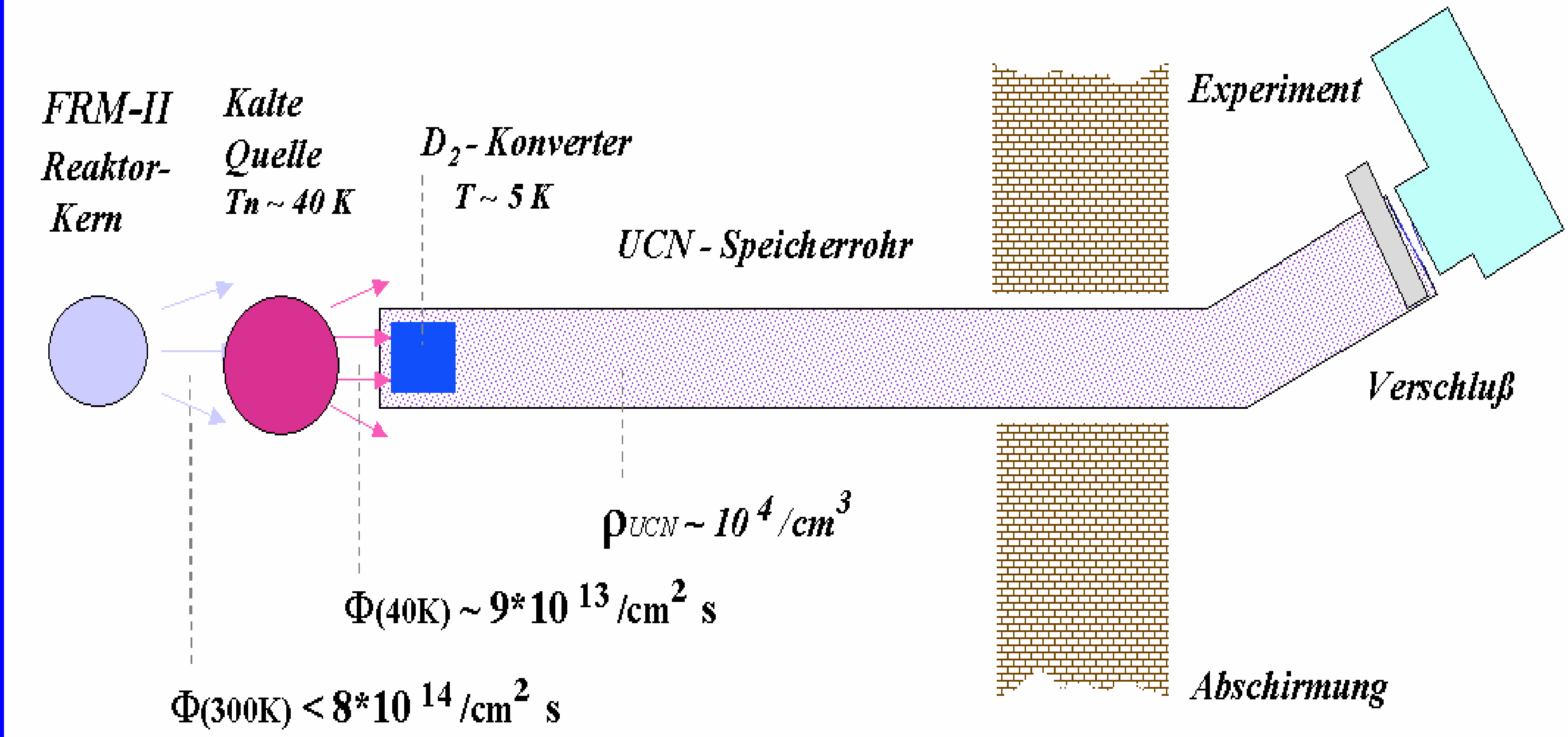




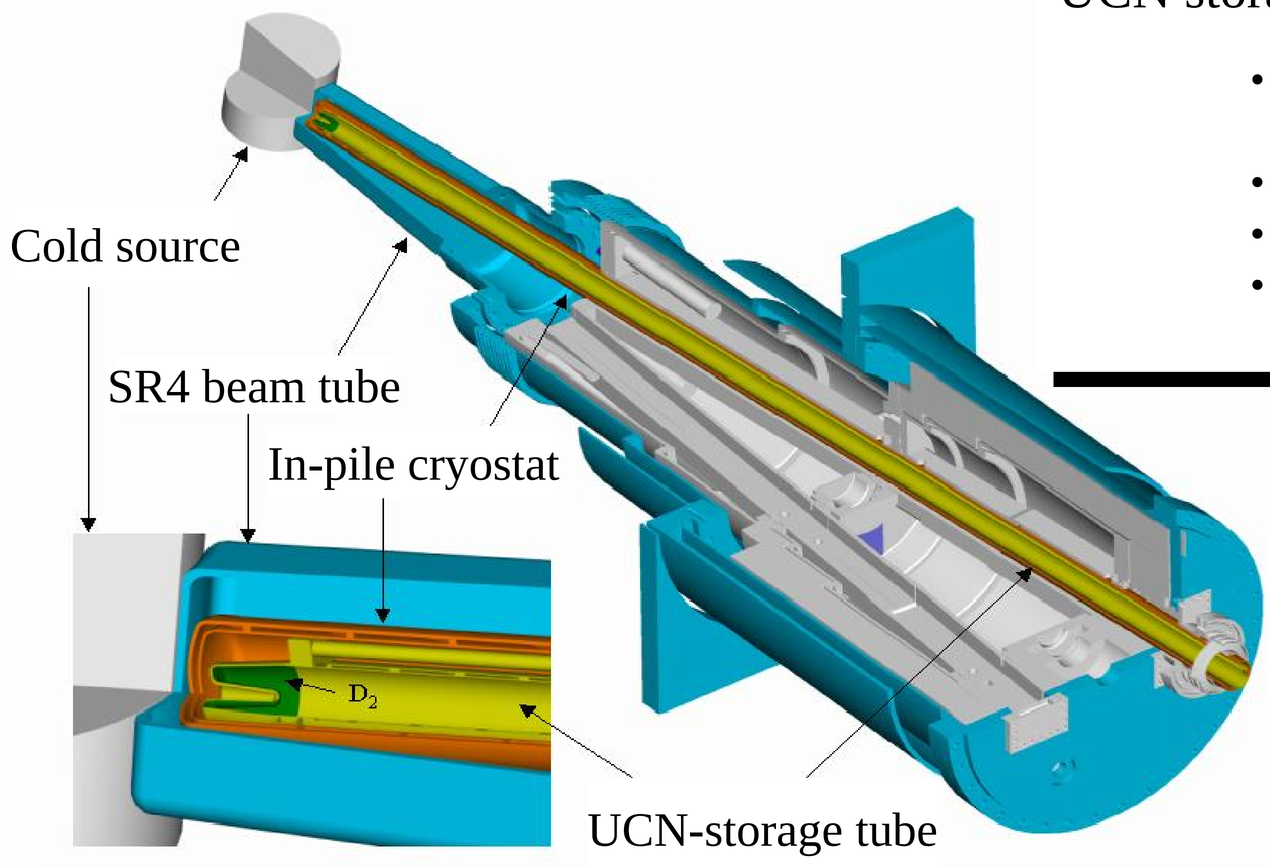
We need a moderator material

- high inelastic scattering cross section
- low absorption cross section
- very low temperature (no heating)

Mini-D_2 (scheme)



Mini-D_2 at SR4



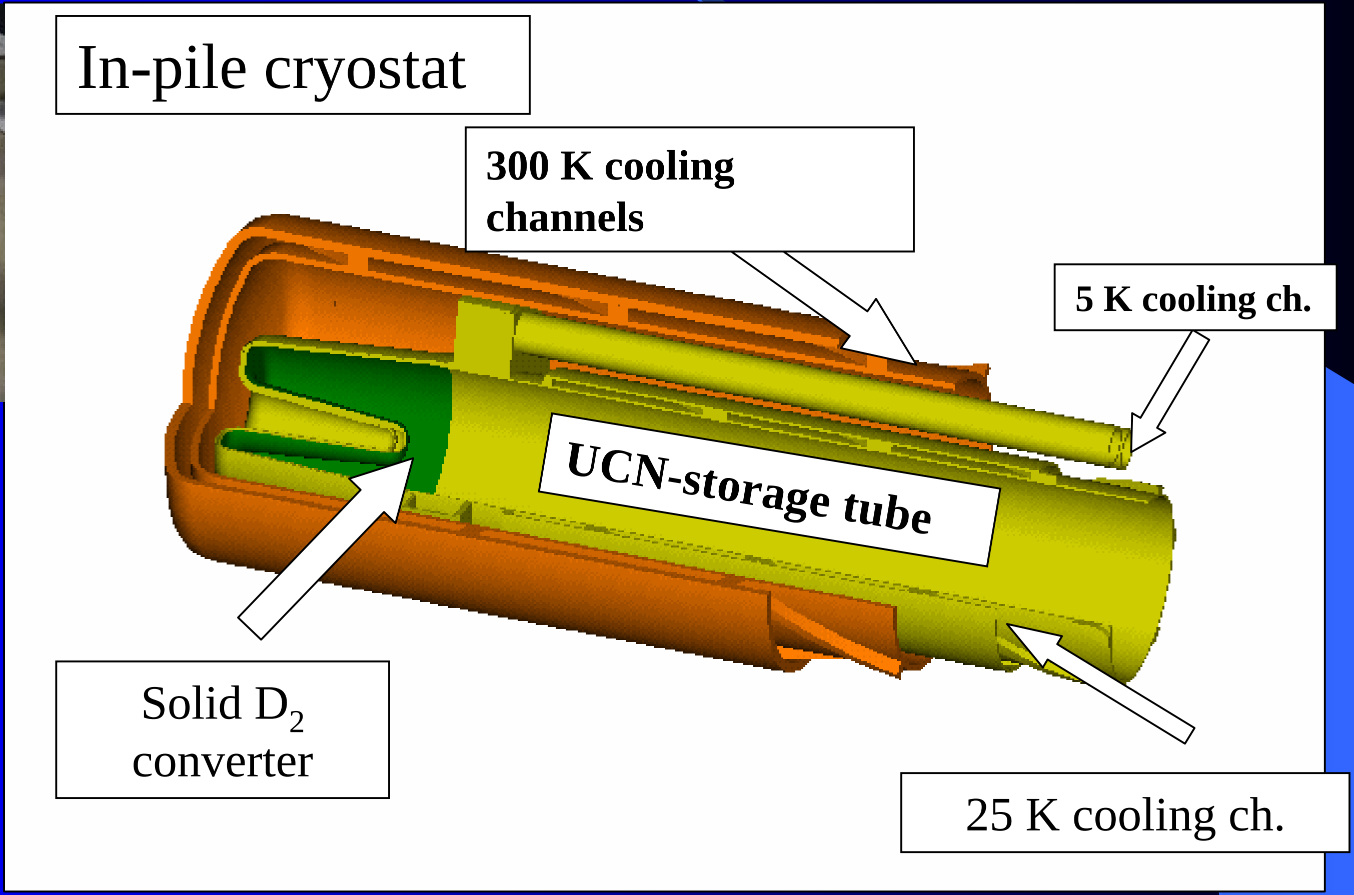
UCN storage tube equilibrium :

- **absorbtion and up-scattering in the converter**
- **losses wall collisions**
- **decay**
- **escape through holes**

The converter

Materials

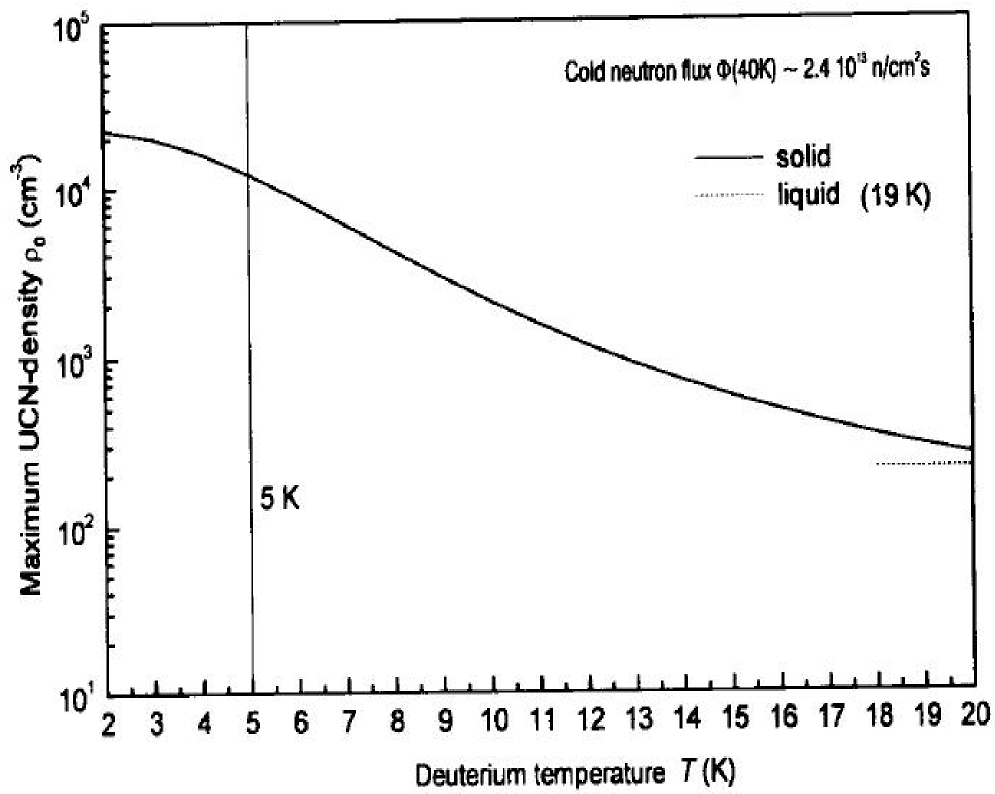
- Solid D_2
- Al6061
- Zirkaloy-4



TUM - UCN density versus temperature of the second moderator ('converter')

Fig. 1

Maximum UCN density in ortho-D_2 for a cold neutron flux $\Phi(40K) \sim 2.4 \cdot 10^{13}$ n /cm^{2}s as a function of the D_2 temperature, as calculated from the phonon spectra in D_2



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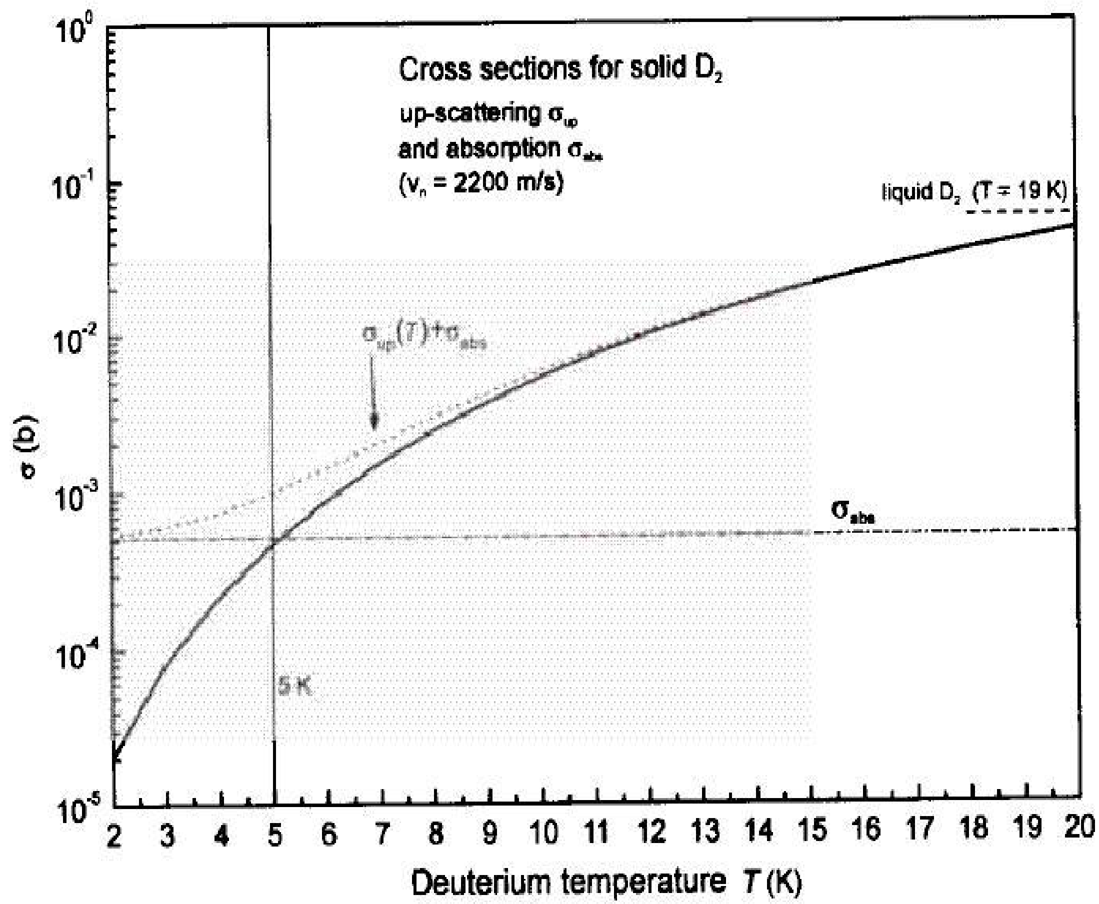
The solid (ortho) D_2 up-scattering cross-section versus temperature

Fig. 2

Cross sections for absorption and up-scattering of neutrons with v=2200 m/s on ortho-D_2 as a function of the D_2 temperature



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Safety aspects

1. Reactor is source of high neutron and gamma flux
2. UCN device will be located inside the biological shield of FRM-II
3. Deuterium is a dangerous (explosive) material
4. Other experimental facilities are planned to work on FRM-II

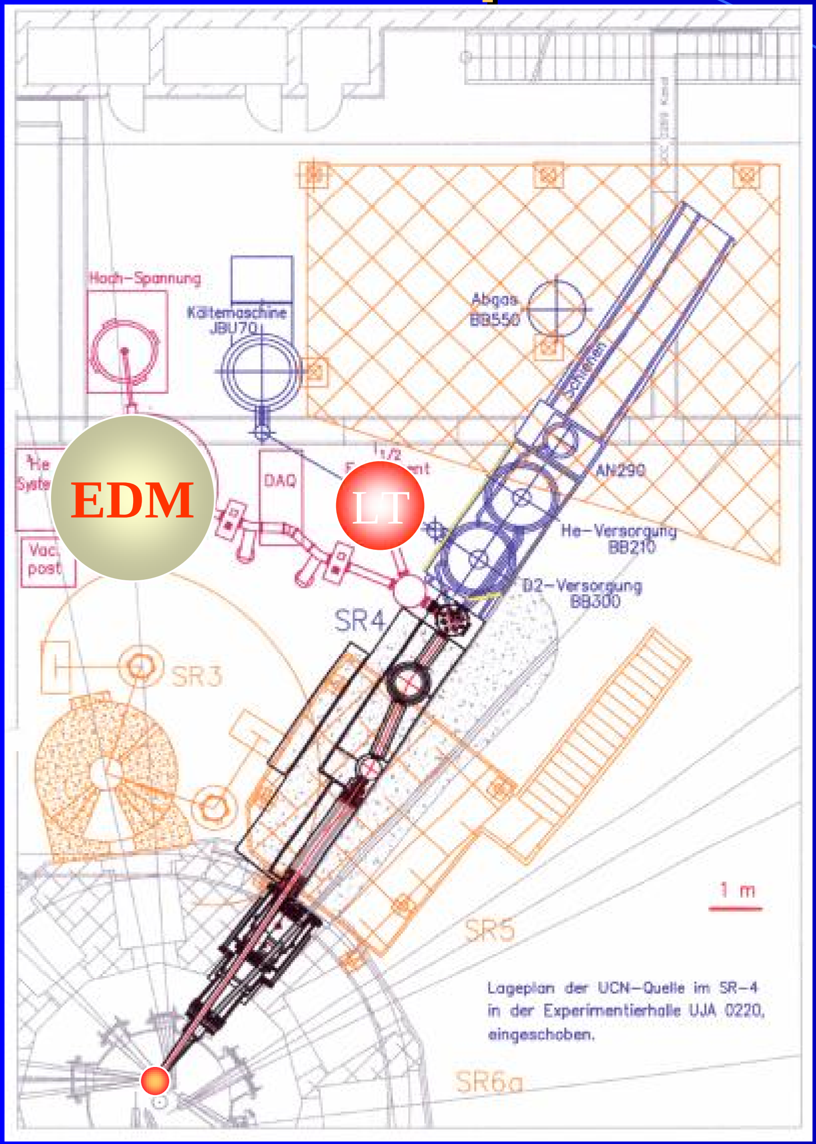
We must guarantee

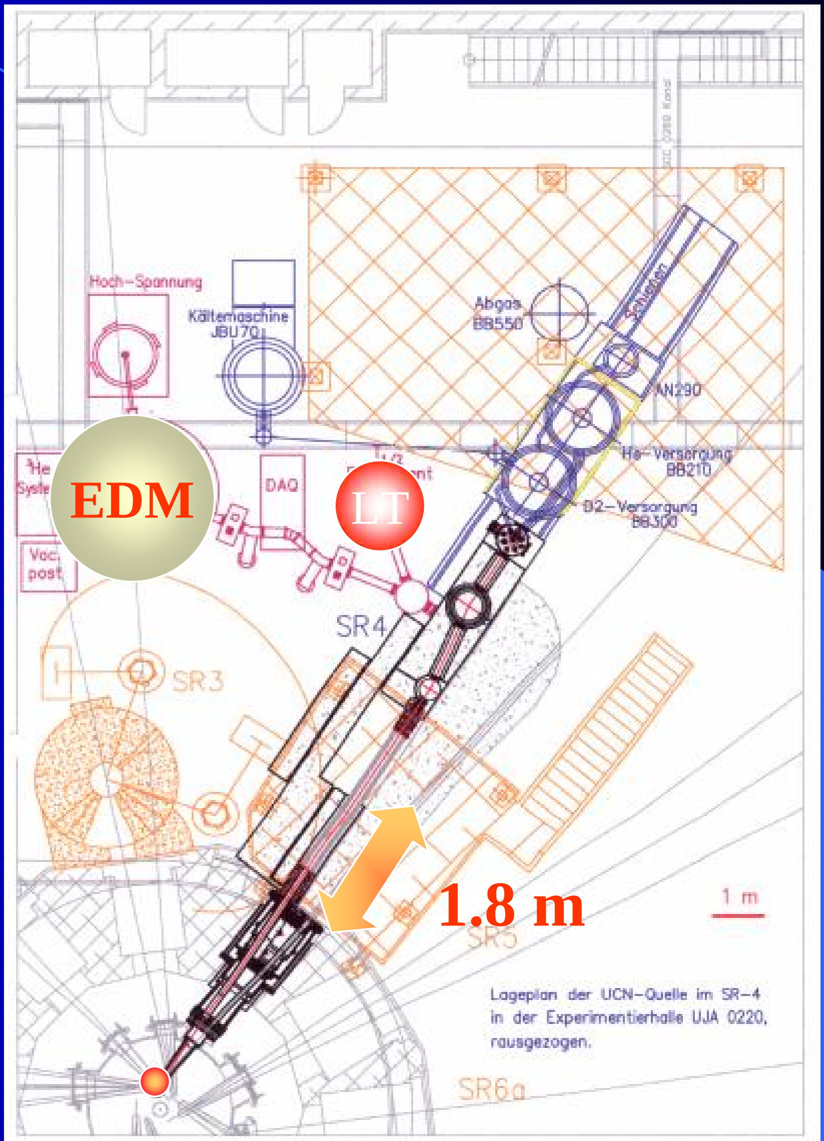
low level of radiation dose

Decoupling of UCN from FRM-II

Double-wall concept of barriers

Floorplan at the FRM-II





Problems related with the use of solid D_2

Goal: Prevent additional absorption of neutrons

- Deuterium has to be sufficiently clean

  $H < 10^{-4}$ and $N_2 < 10^{-5}$ atomic concentration

- Small percentage of para-D_2

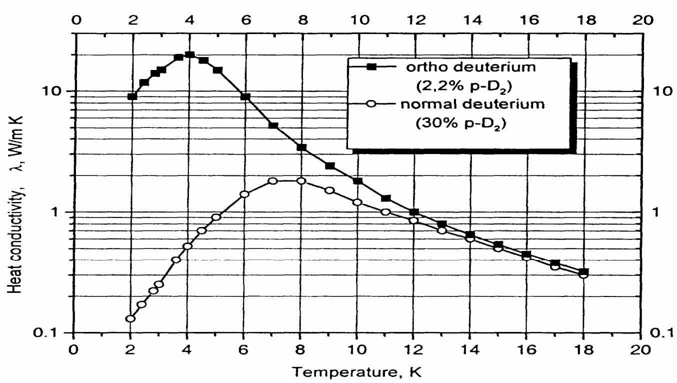
  (high up-scattering cross section – heating)

  $X_{para} < 5*10^{-3}$

- Thermal conductivity of solid D_2

  (good cooling system)

Temperature dependence of the thermal conductivity of solid deuterium for various ortho/ para compositions.



As, above 4 K, the thermal conductivity of ortho-D_2 decreases drastically with temperature, good cooling of the converter is very important (cold finger).

Para and Ortho deuterium

Natural D_2 is a mixture of two possible compounds, having different nuclear spin S and orbital angular momentum J:

- Ortho-D_2: S=0,2 ; J=even (0,2,...)
- Para-D_2: S=1 ; J=odd (1,3,...)
- Room Temperature: D_2 is mixture of 1/3-para, 2/3-ortho
- Energy difference of first para to ortho state (J=1 -> J=0) is approximately 7meV
- Inelastic scattering of UCN with para-molecules leads to high energy transfer to the UCN, which means that this neutron is no longer ultracold (upscattering)

Conversion pD_2 -> oD_2

- Not possible for isolated molecules! (Transition $\Delta J=1$ and $S=1$ -> $S=0,2$)
- Induced by an inhomogeneous magnetic field.
- Self conversion:

  Interaction with the dipol or rotational magnetic moment of a neighbouring molecule:

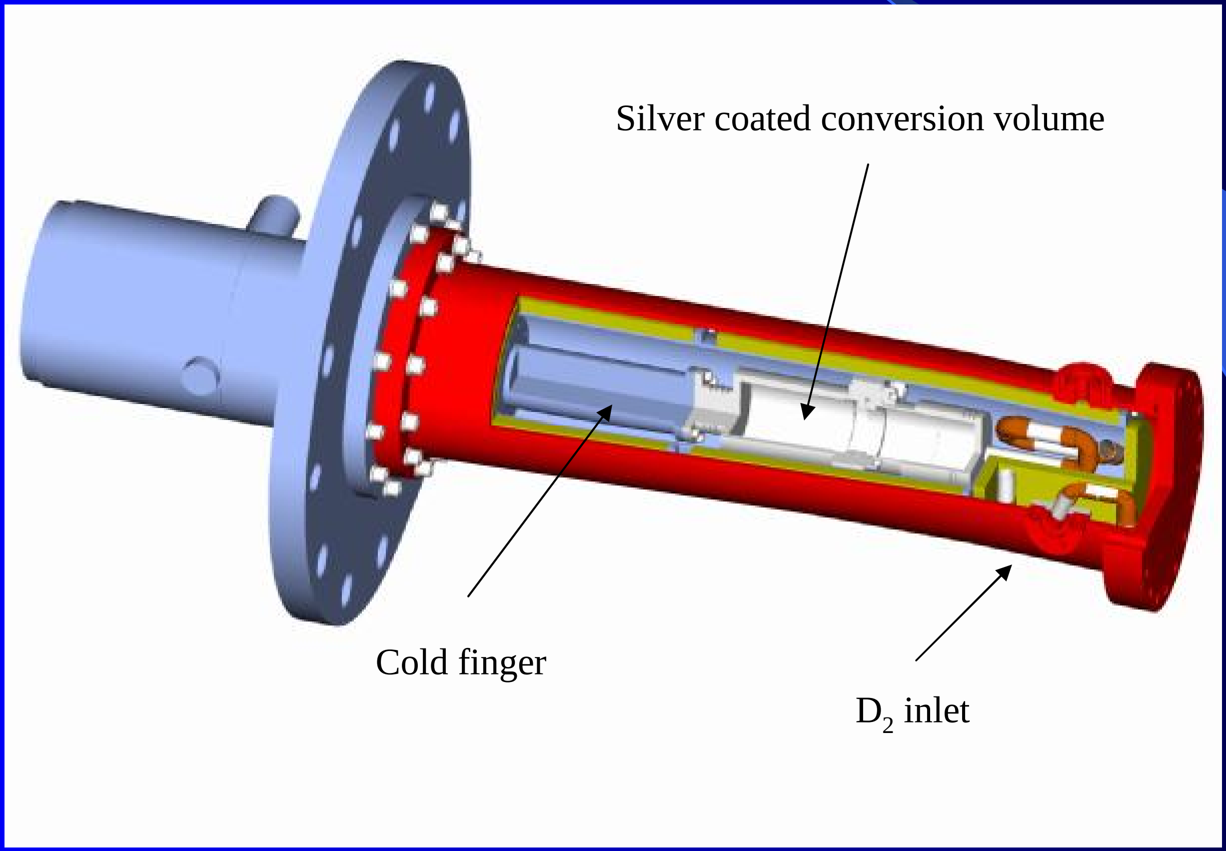
$$m_D = 0.8574 m_N$$
$$m_{rot} = 0.4429 m_N$$

  Conversion rate: $K = (0.060 \pm 0.003)\% h^{-1}$ $\propto m_D^2 \cdot m_{D,rot}^2$

- Induced by magnetic centres $(m = O(m_B))$: ($Fe(OH)_3$, O_2, Ag)

  Reduction of the conversion time from months to hours.

The Coldhead



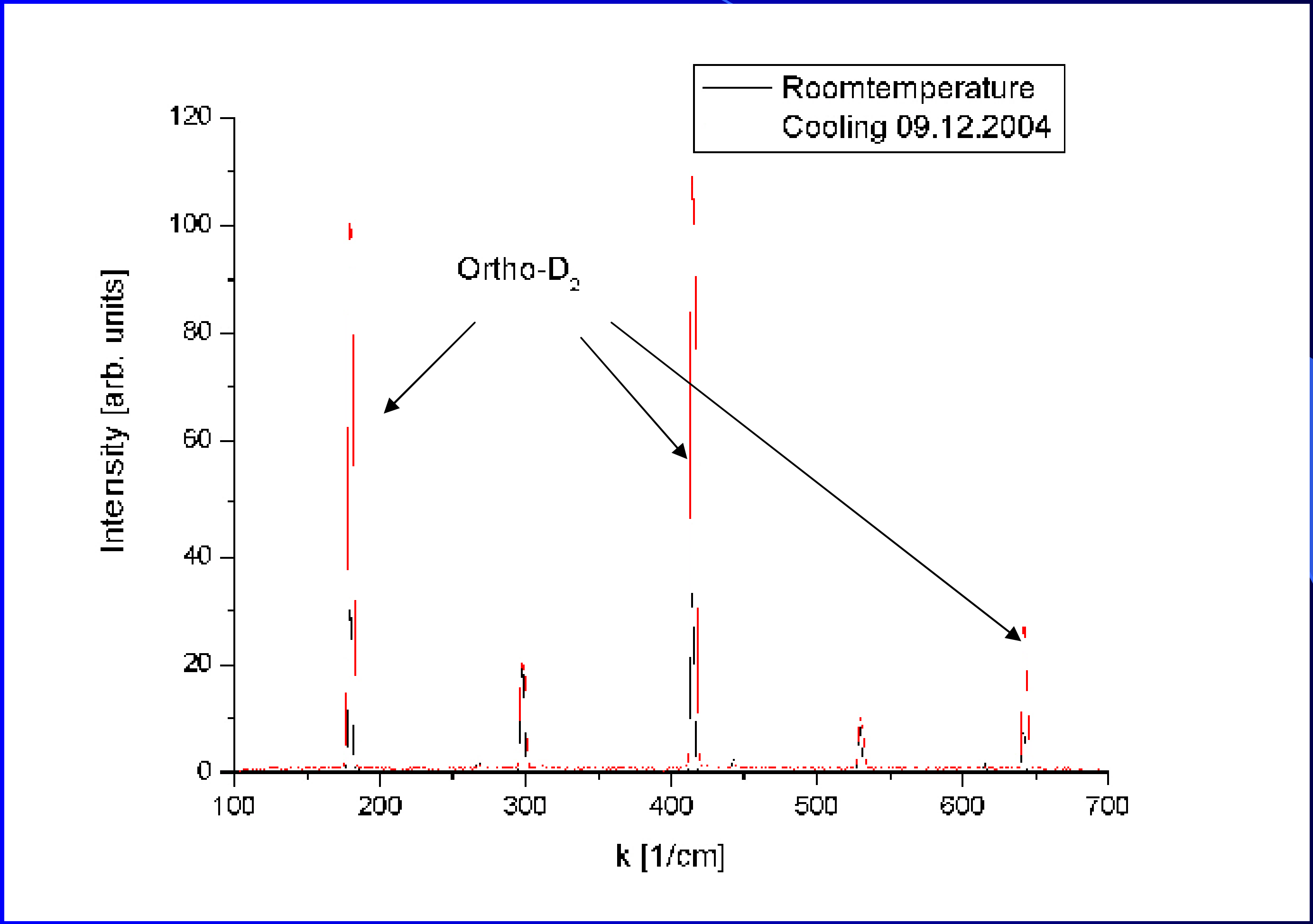
Raman spectroscopy

- inelastic scattering of photons with molecules
- molecules get stimulated to a higher energy state (rotational or vibrational energy)
- frequence of incoming light is shifted to certain levels
- spectral analysis can detect this shifted frequencies

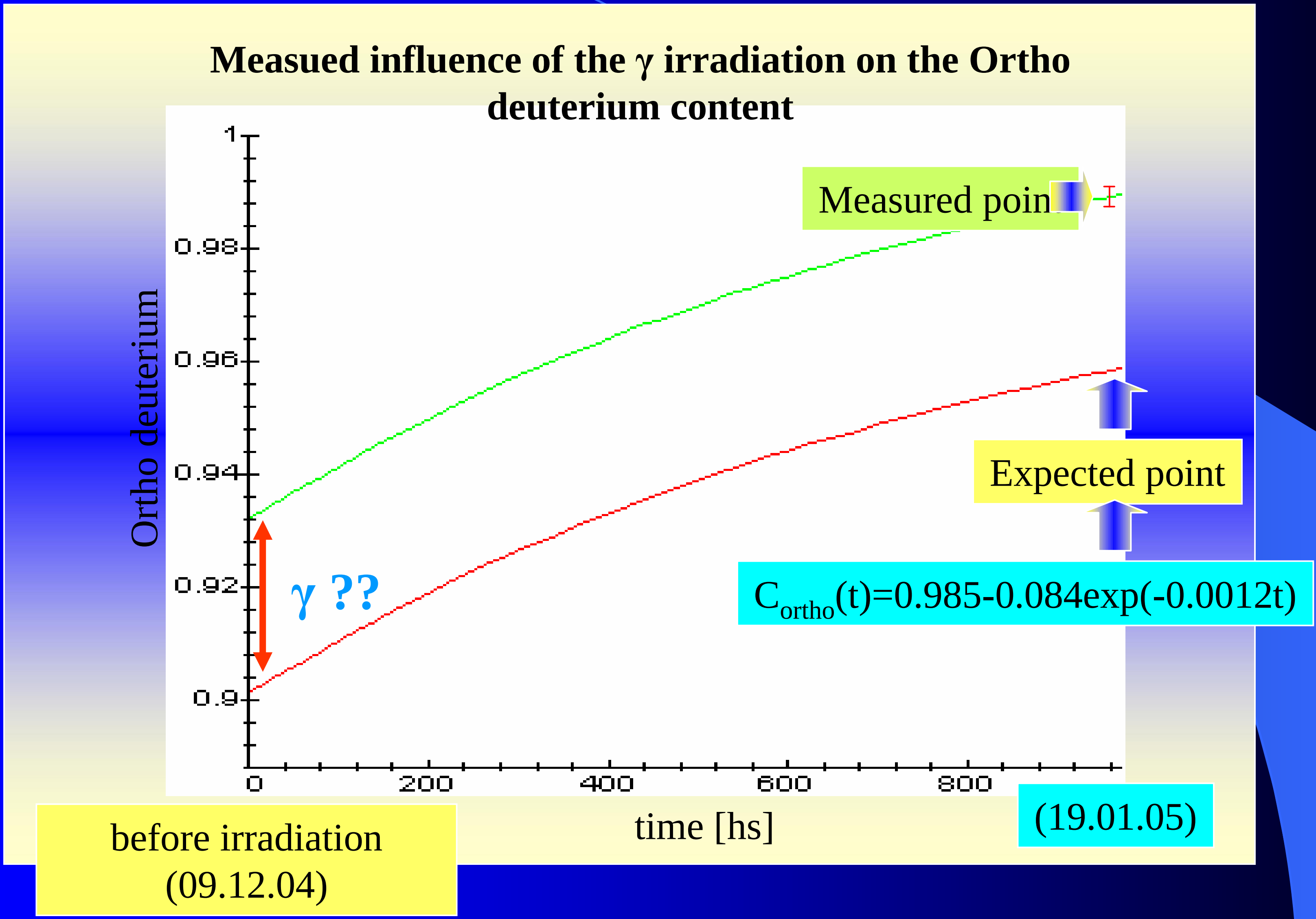
Our special case:

The integral over two peaks in the spectrum build a ratio between para and ortho deuterium

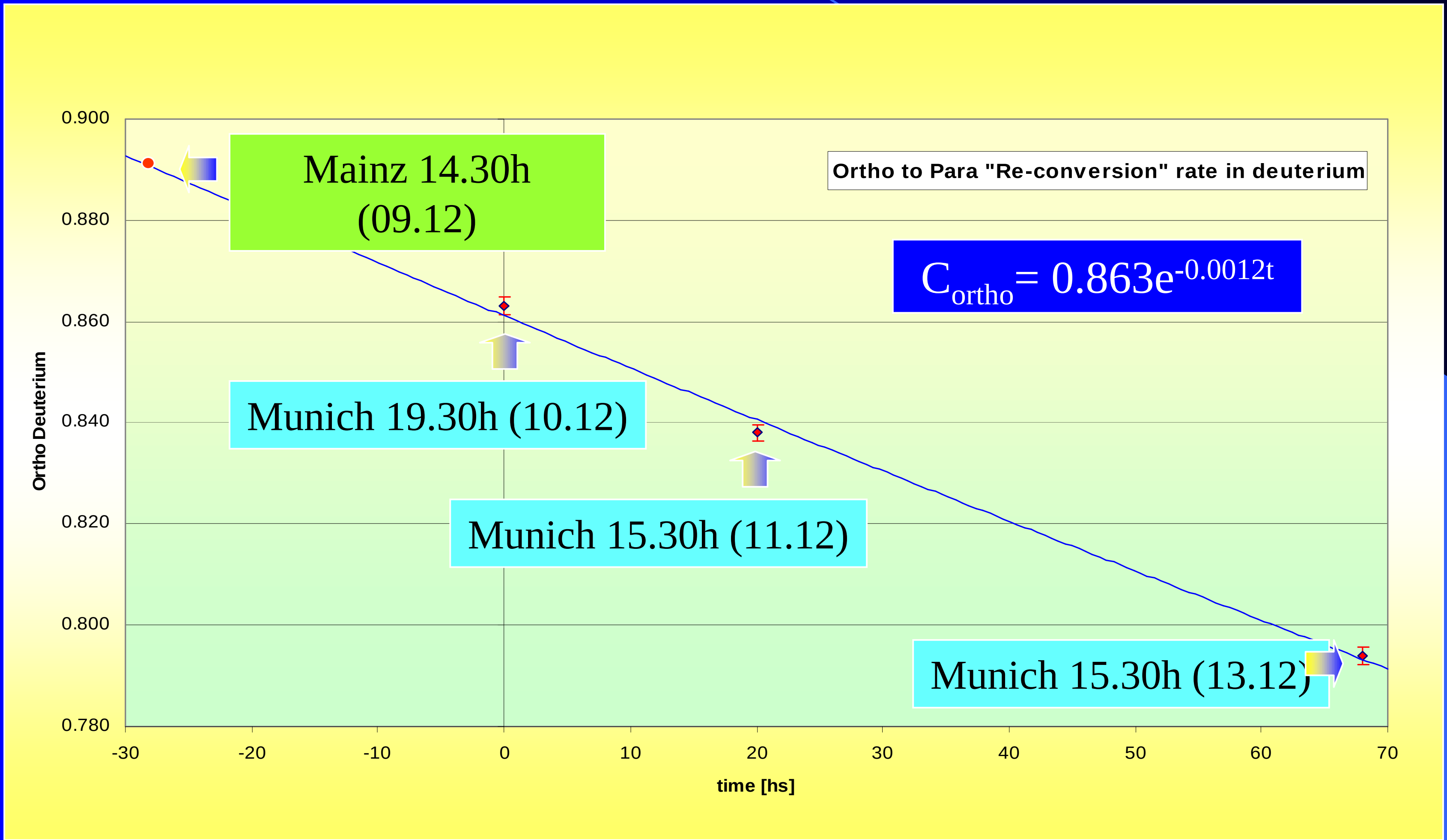
Raman results



Conversion by radiation



Ortho-Para-Reconversion



T raining
R esearch
I sotopes
G eneral
A tomics

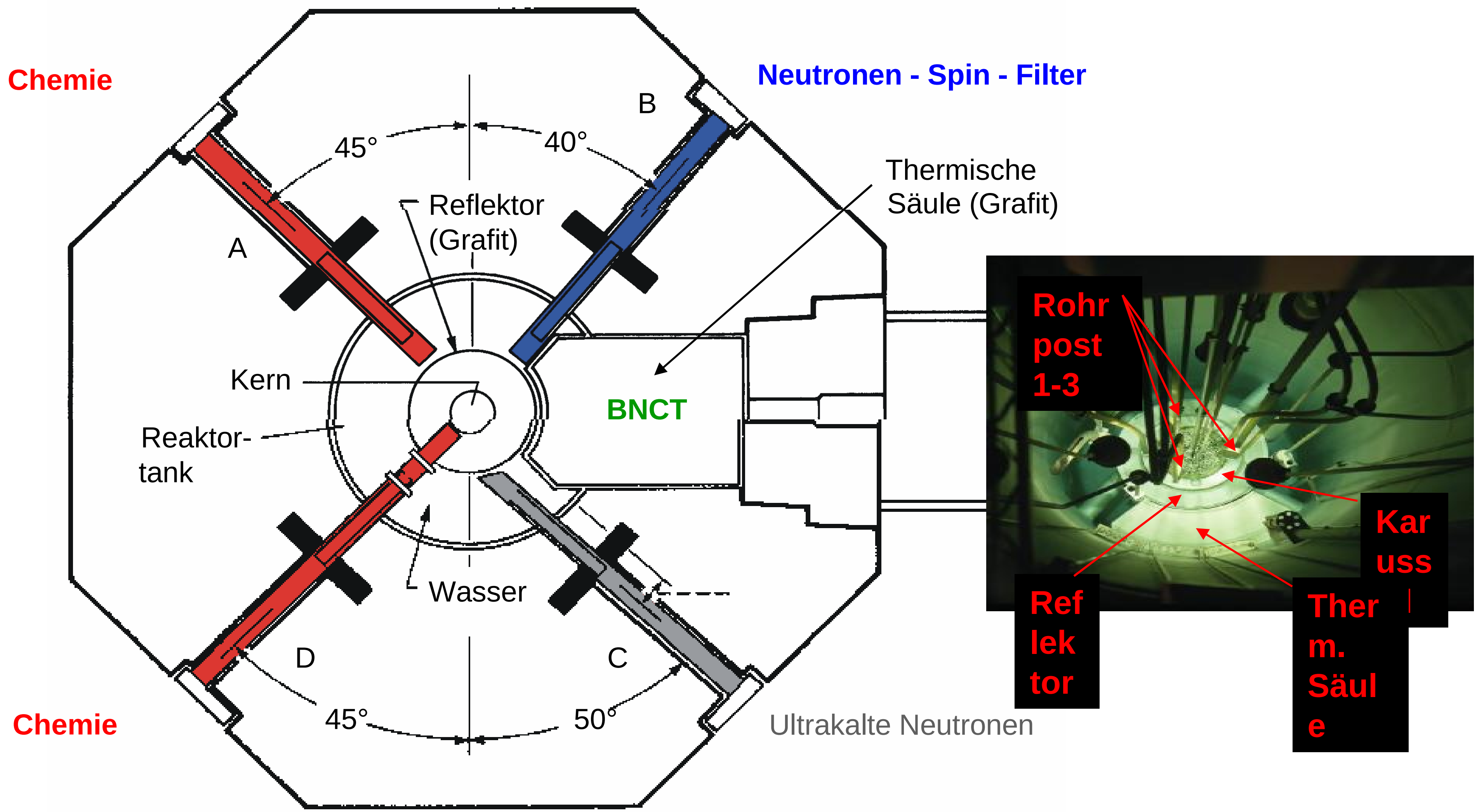
Mark II

at Mainz

power: $100\ kW_{th}$ (steady)

$250\ MW_{th}$ (pulse mode)

Aufbau TRIGA Mainz



Strahlrohre: Schnelle Rohrpost (Förderzeiten 0.5 s)

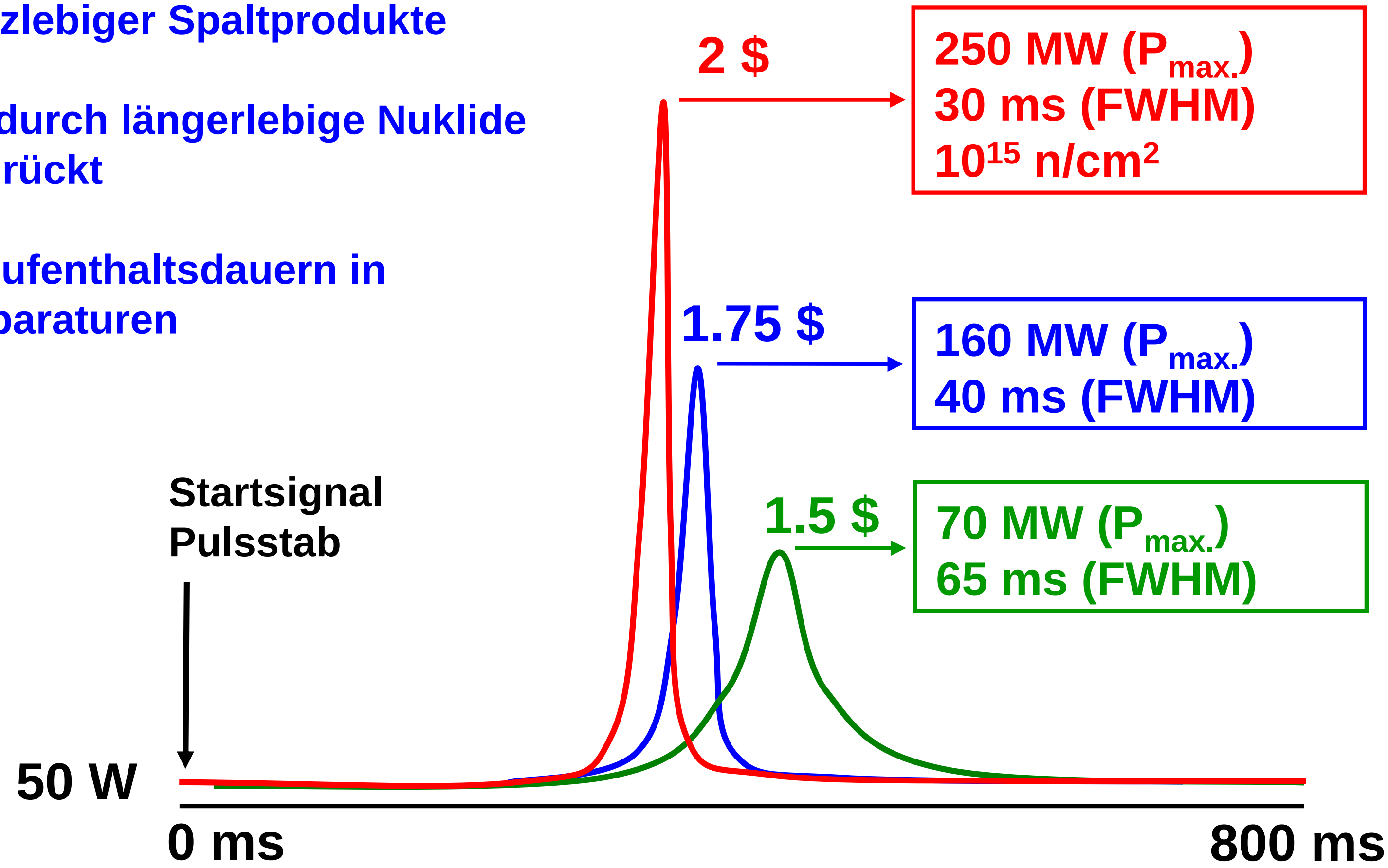
Gas-Jet Transportsystem (U, Pu, Cf-Target)

Pulsbetrieb

- Erzeugung kurzlebiger Nuklide für die NAA
- Herstellung kurzlebiger Spaltprodukte

→ Interferenzen durch längerlebige Nuklide werden unterdrückt

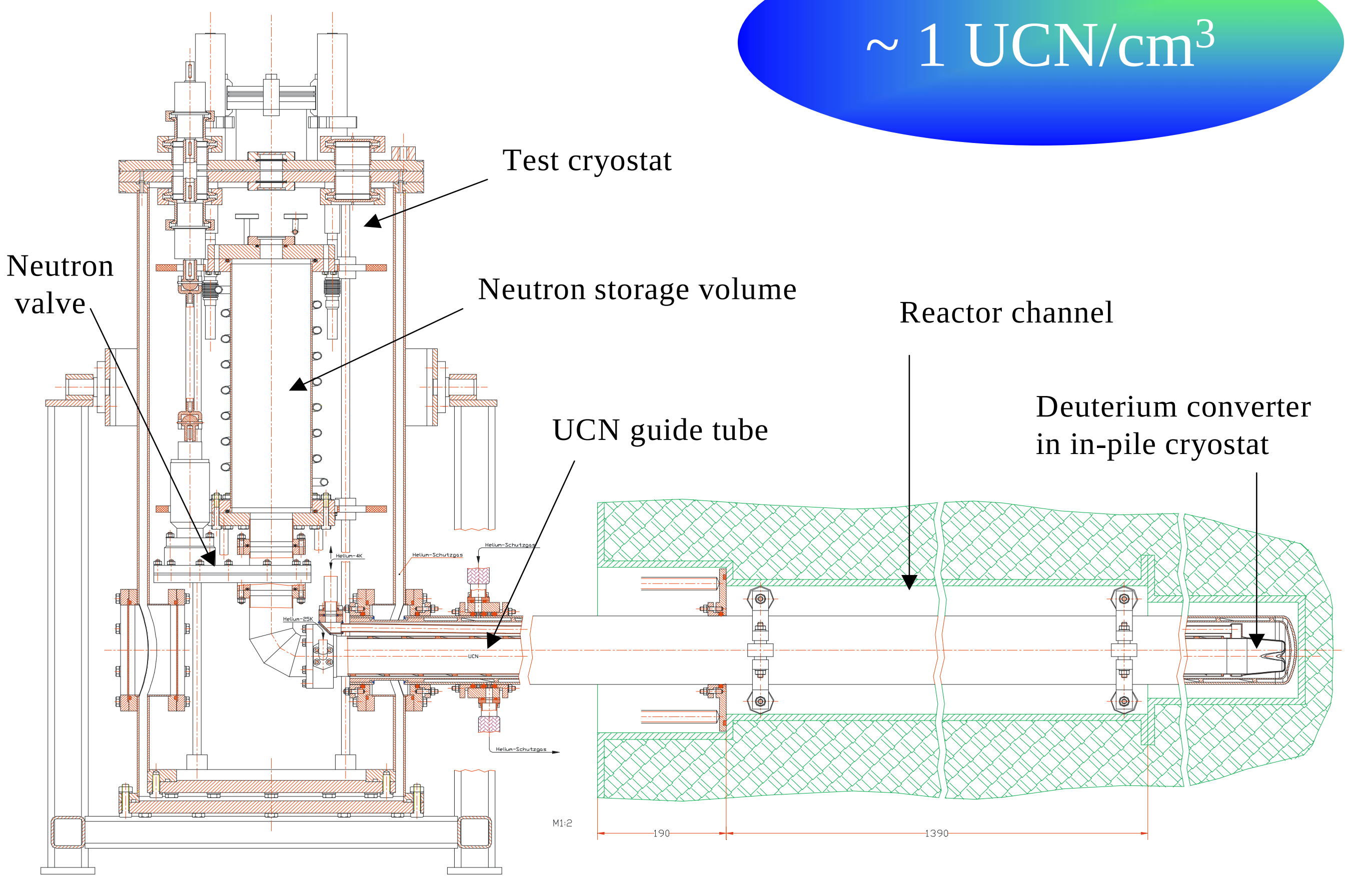
- Messung von Aufenthaltsdauern in chem. Trennapparaturen



Für 2 $-Puls gilt: $Akt._{Puls}/Akt._{Sätt.} = 55\ s/T_{1/2}[s]$

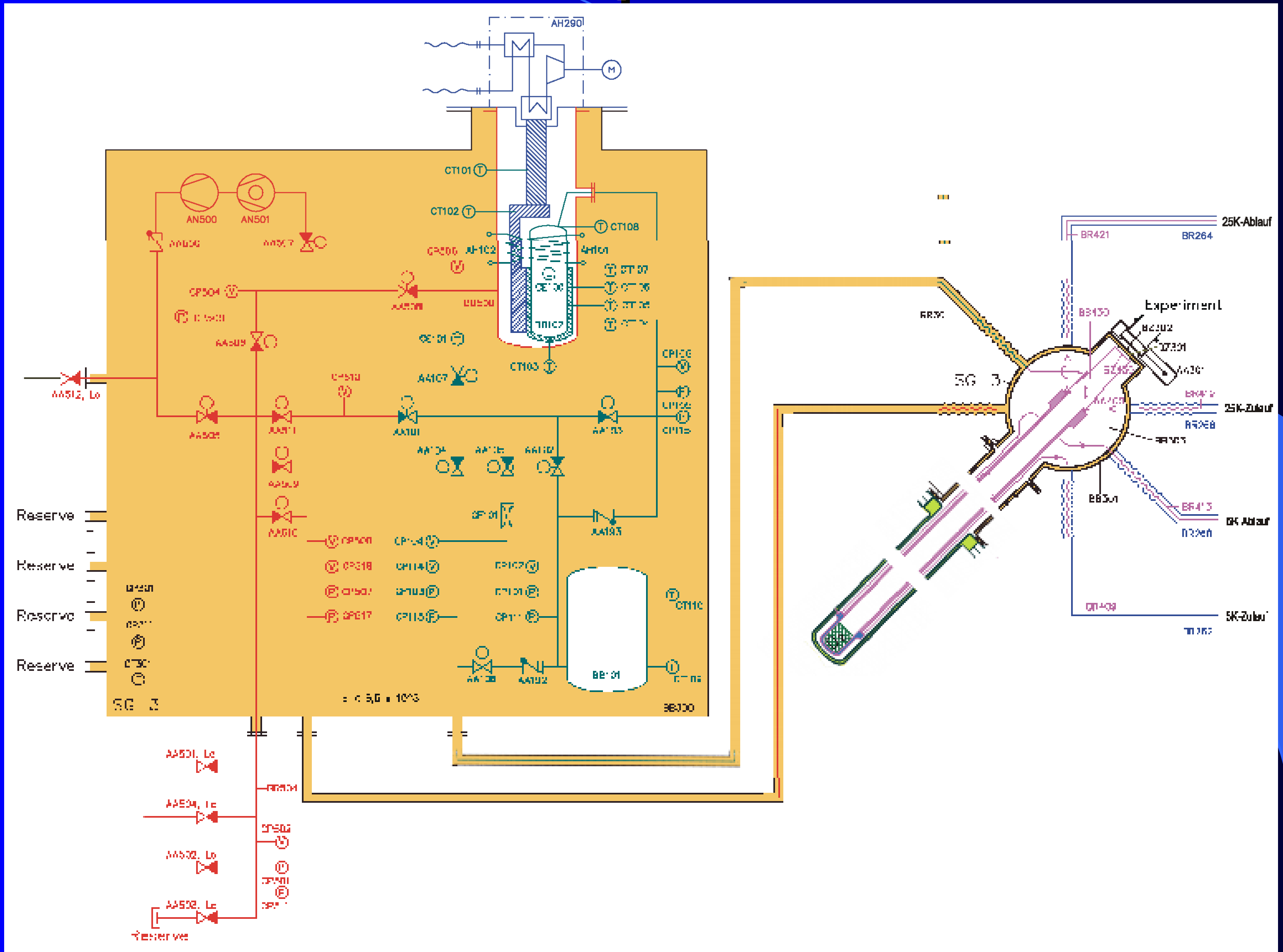
The TRIGA Mainz setup

~ 1 UCN/cm^3

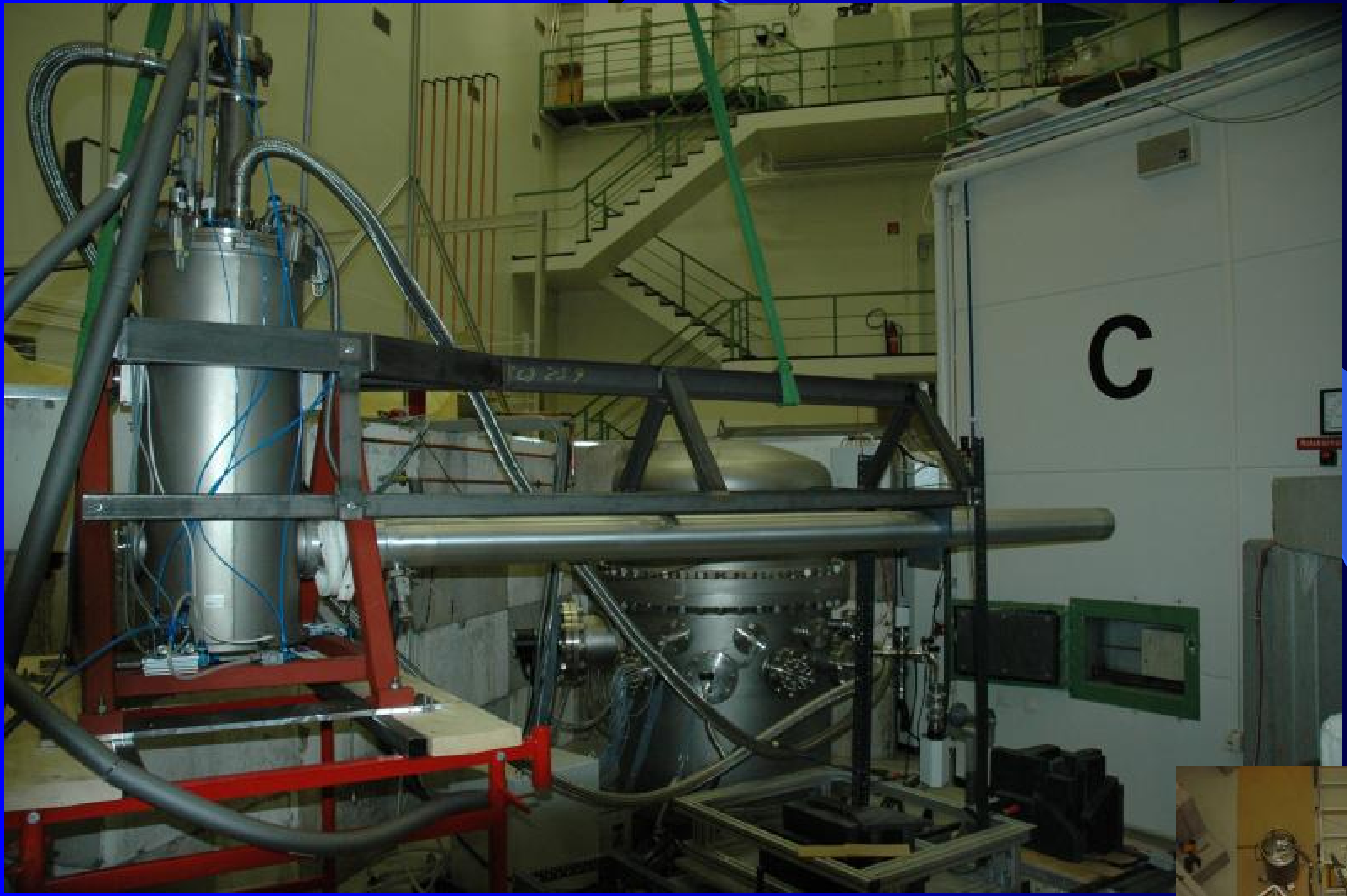


pulsed neutrons

TRIGA setup flowscheme



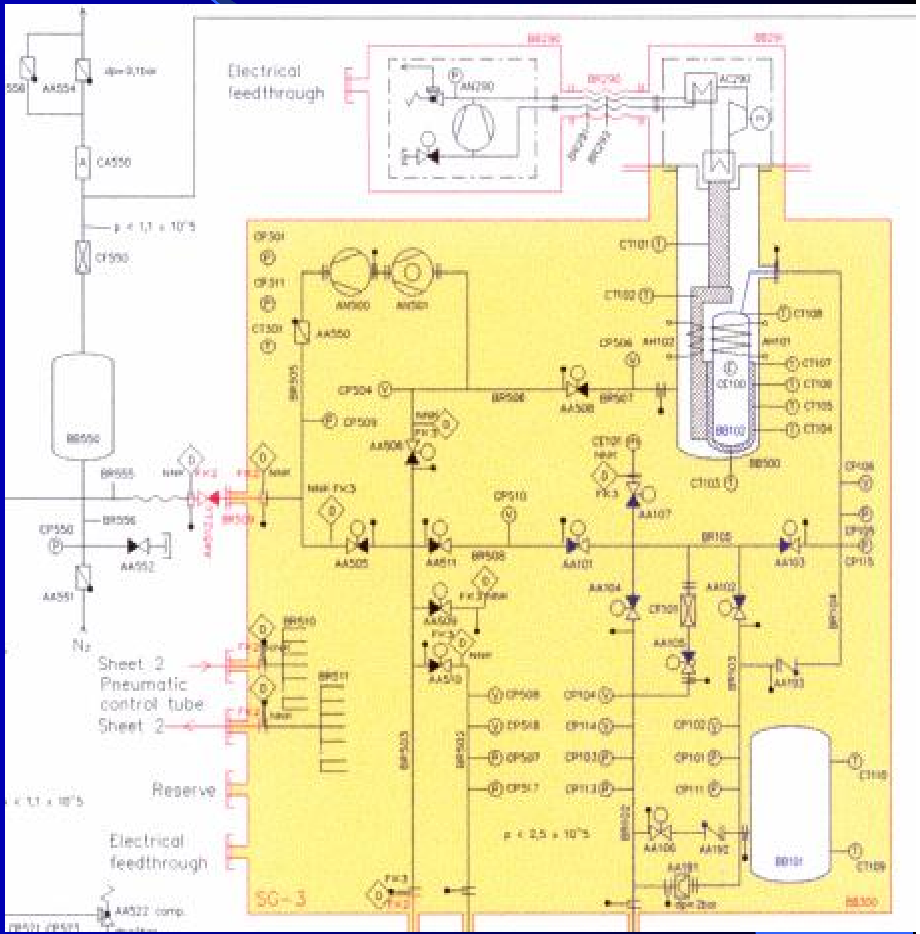
Testcryostat in reality



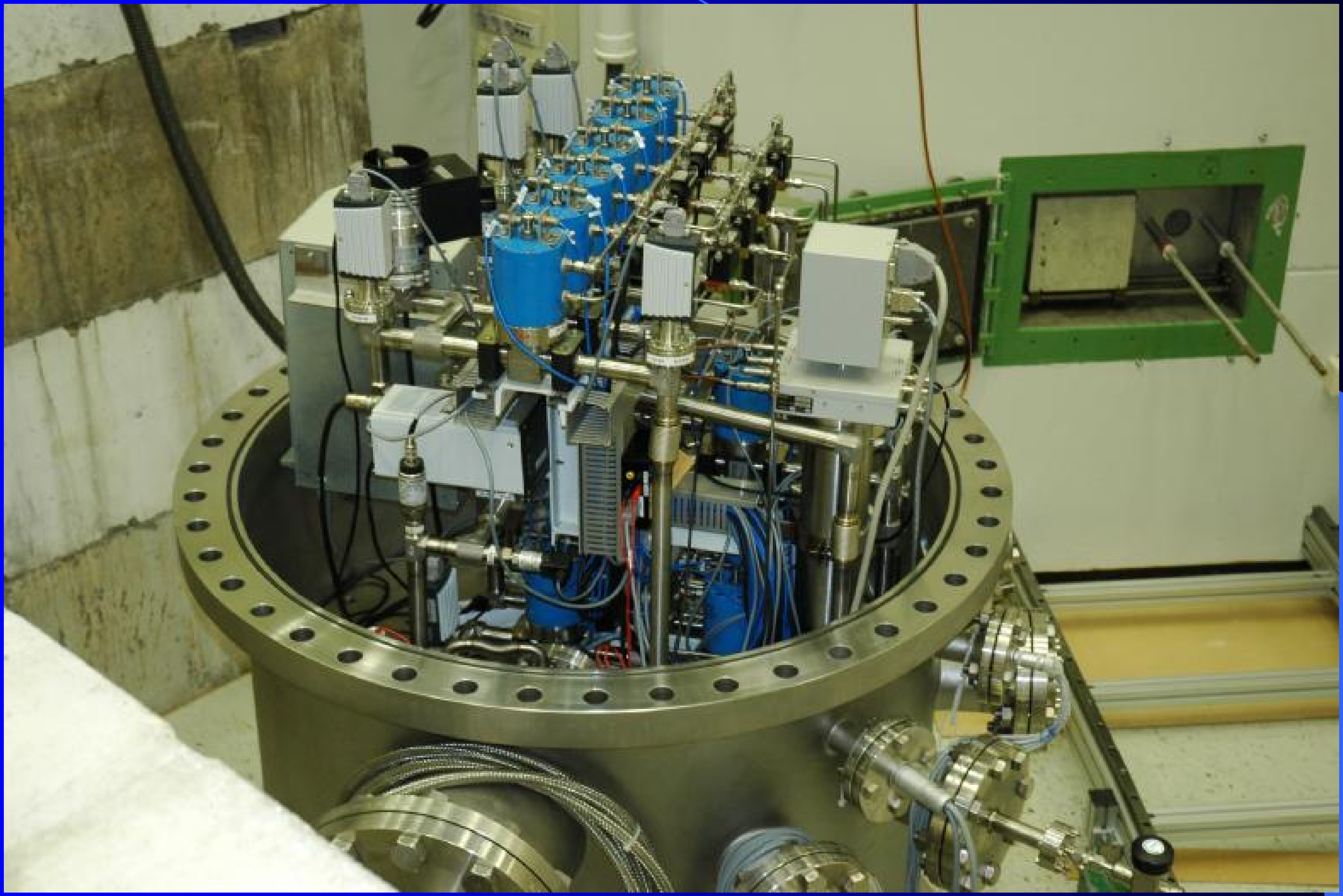
The D_2 gas system

Functions

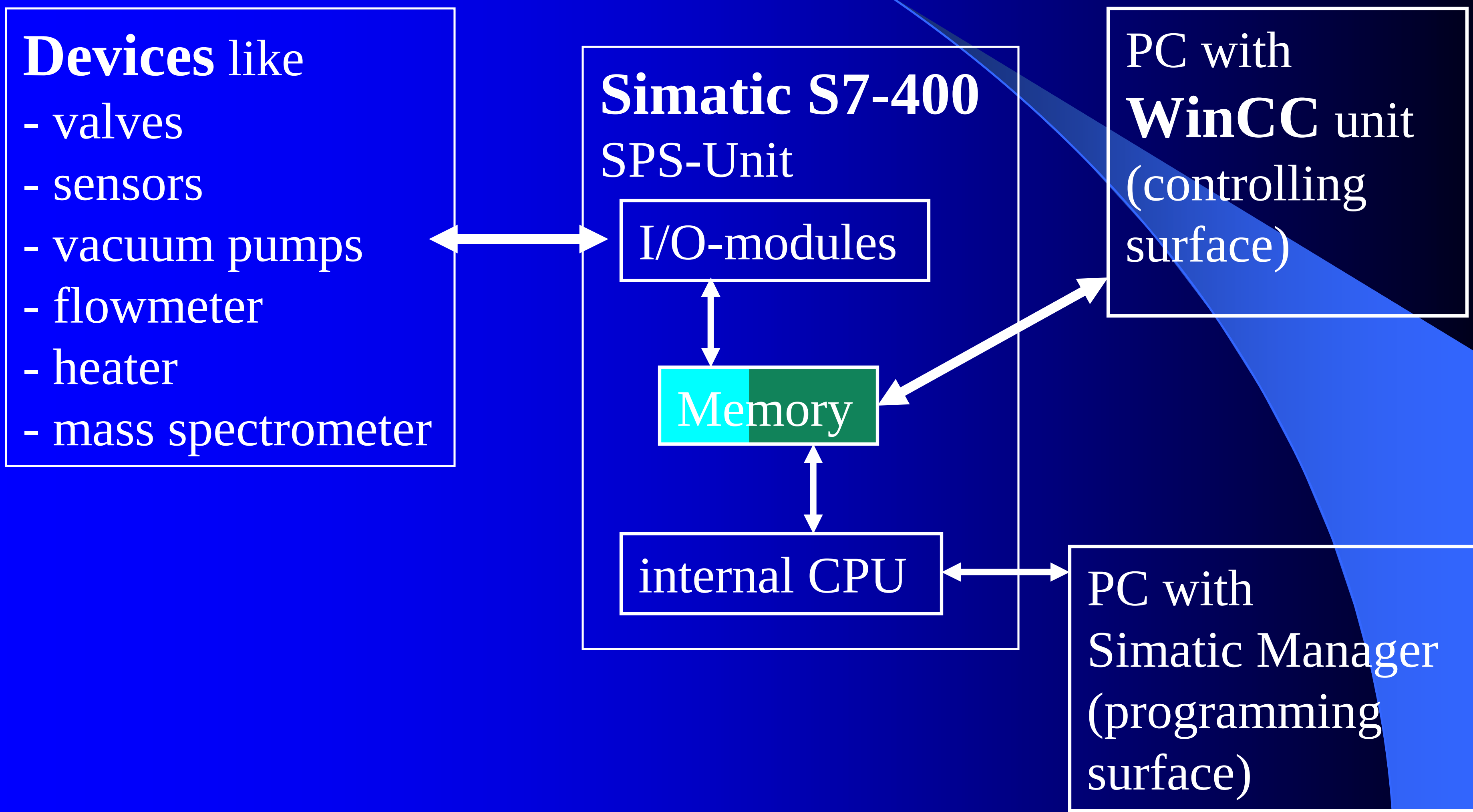
- Produce a vacuum in the system and in the testcryostat
- Store deuterium at low temperature (solid) or in gasous state (300 l)
- Check the purity with a mass spectrometer
- Convert p-D_2 to o-D_2
- Software control system



Gas system in reality



Controlling with redundancy



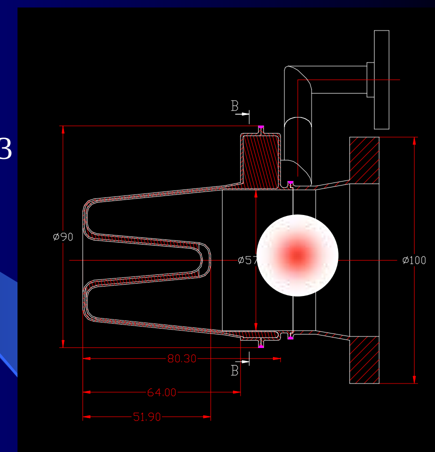
Heating phenomena

Steady (FRM-II)

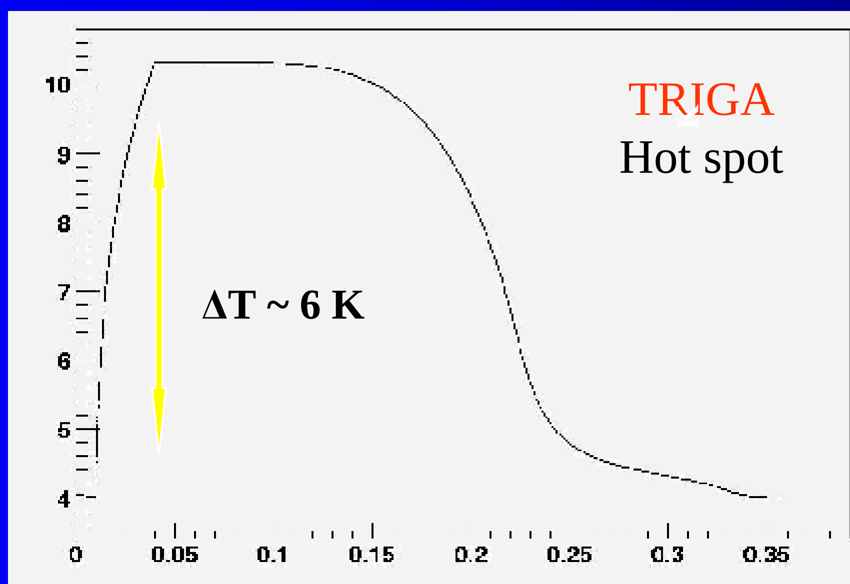
- Solid D_2 ~ 0.14 W/cm^3
- Al6061 ~ 1.8 W/cm^3

Pulsed (TRIGA)

- Pulse (30 msec) ~10.3 W/cm^3
- Time between pulses 10 min.



Ortho-Para Deuterium conversion



T [K]

Time [s]

The christmas shot

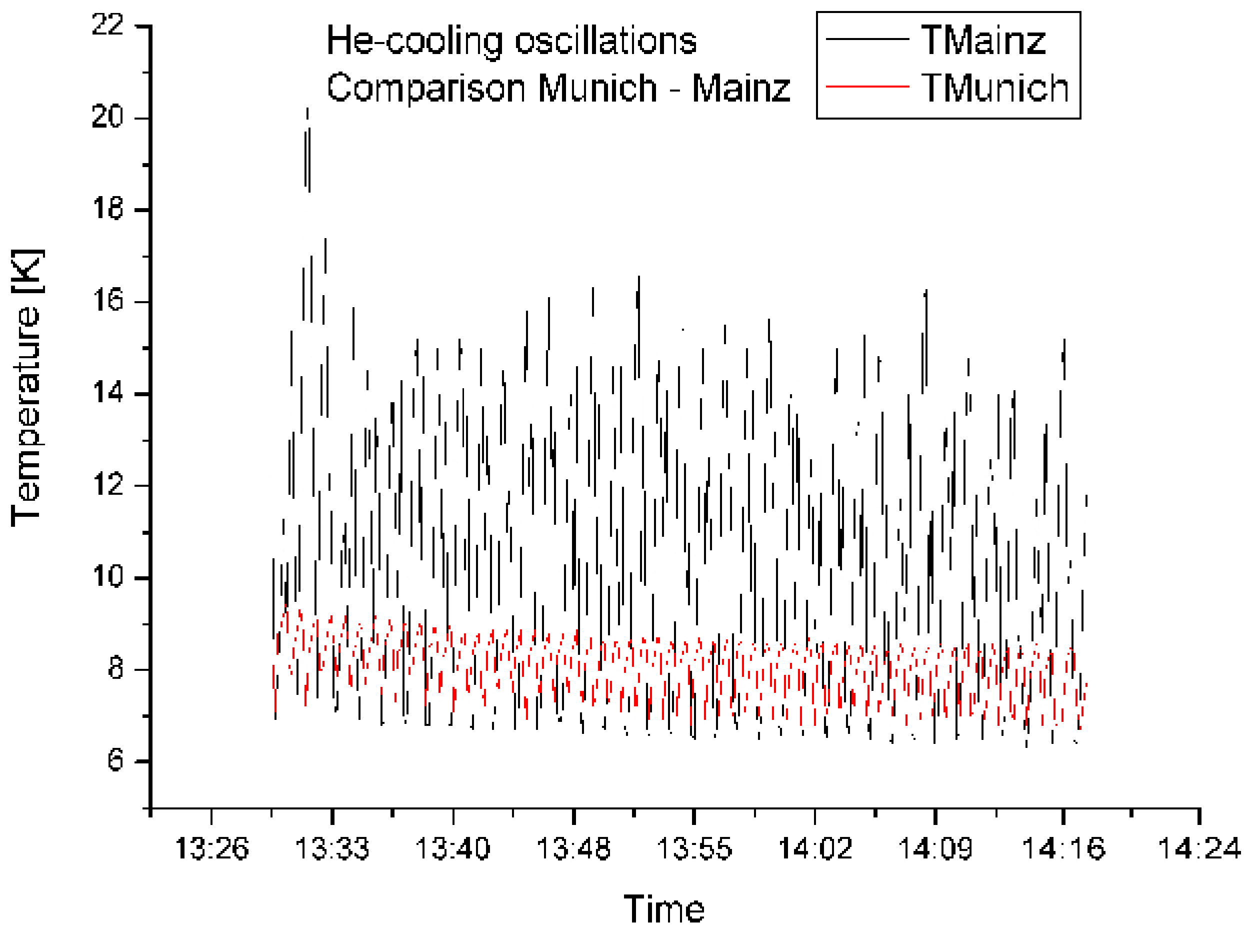
- First try of UCN production in Mainz: 22.12.2004
- Several problems occured:
- UCN-Detectors were broken after transport to Mainz
- High radiation background measured
- Temperature oscillations in He-cooling

=> New detectors have to be installed

⇒ Detectors have to be shielded against background

⇒ He-cooling oscillations have to be reduced

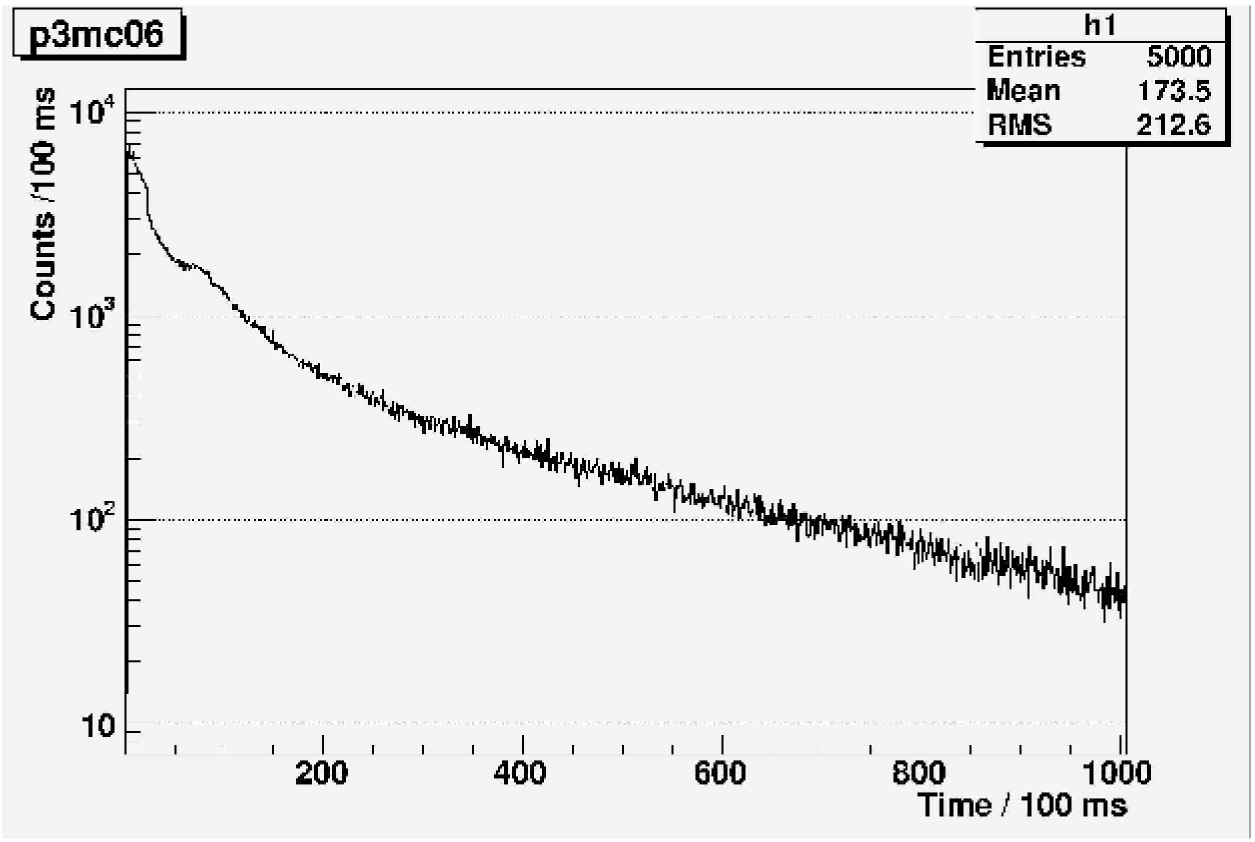
He-cooling oscillations



Problems with He-cooling

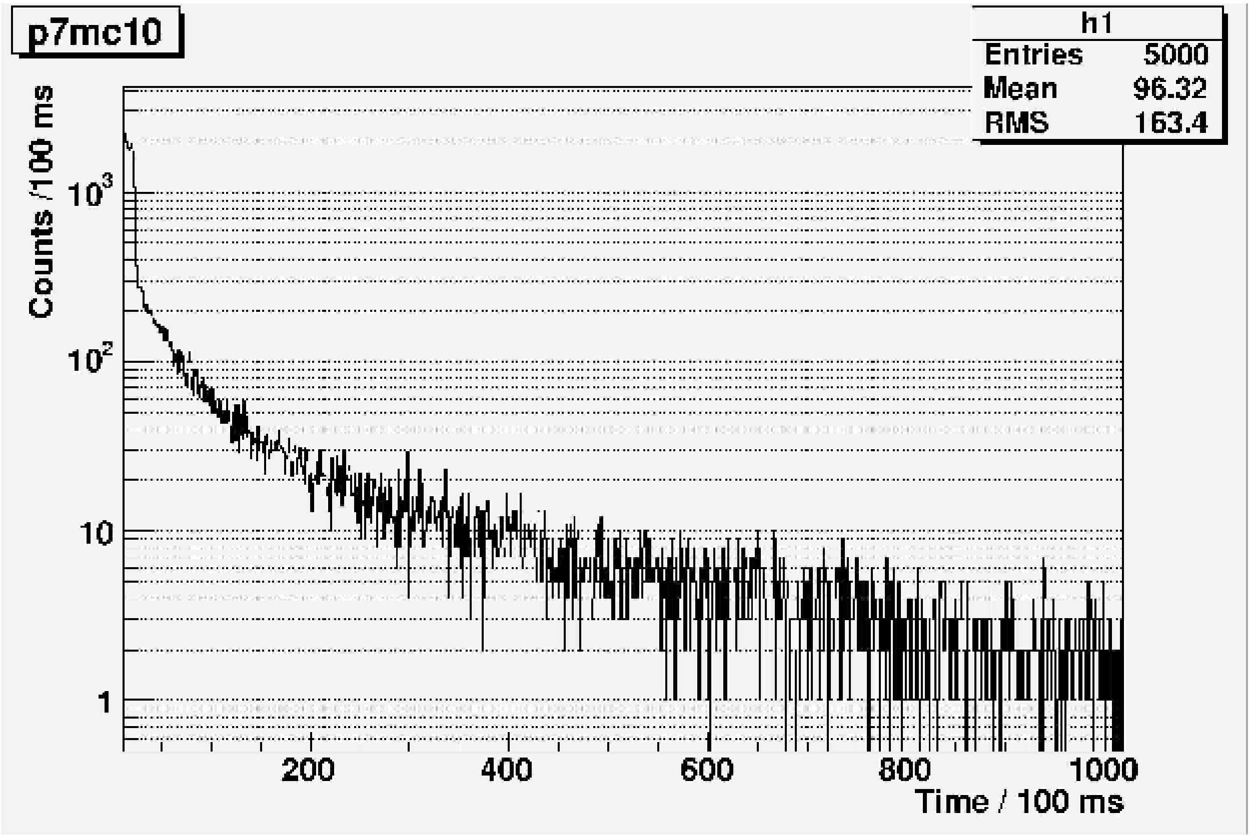
- Big amplitude of oscillations leads to big oscillations in vapor pressure (0.001mbar to 1mbar)
- More UCN losses due to absorption and inelastic scattering
- Currently the source of the bigger oscillation amplitude not fully understood
- Further investigations are necessary

Problems with background



Unshielded detector

Background problems



Shielded detector

Outcome of christmas shot

Results:

- Gas system works fine
- Sufficient cooling (no melting of deuterium)
- Control and steering system is functional
- Shielding of detector has to be improved
- He-cooling problems have to be solved

Outlook

• Newest measurements (PSI group) indicate, that conversion of neutrons with a deuterium converter corresponds with the calculated values

• The TRIGA experiment can also proof this calculations and can extend them to the case of a pulsed reactor

• Combining these results with a high neutron flux reactor as the FRM-II shows, that Mini-D_2 can be a new powerful UCN-source

8.9 A neutrons are needed to create UCN in ^{4}He

2.1 A new method for UCN production

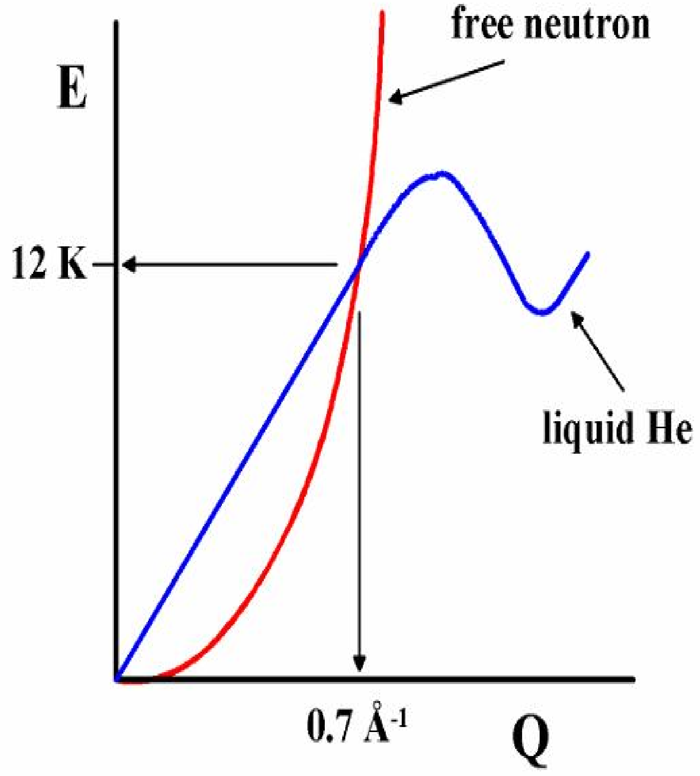
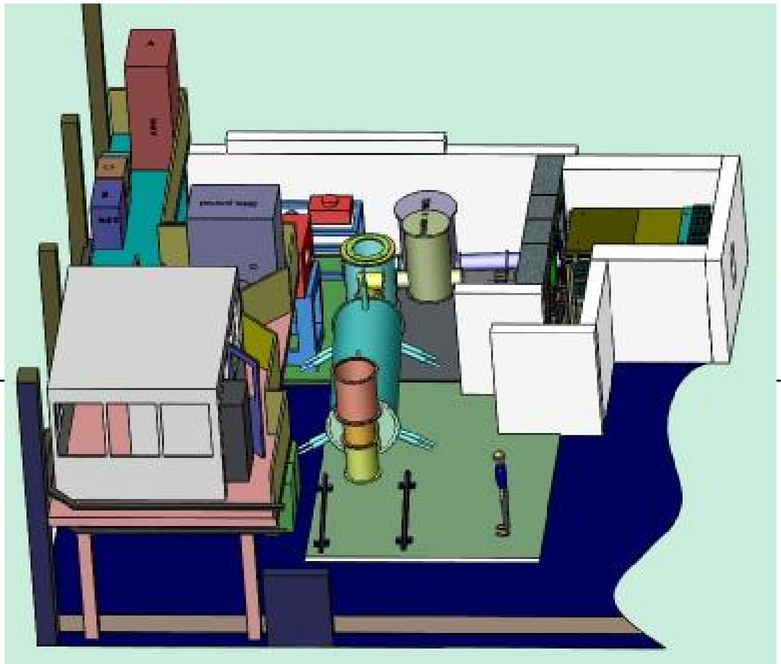
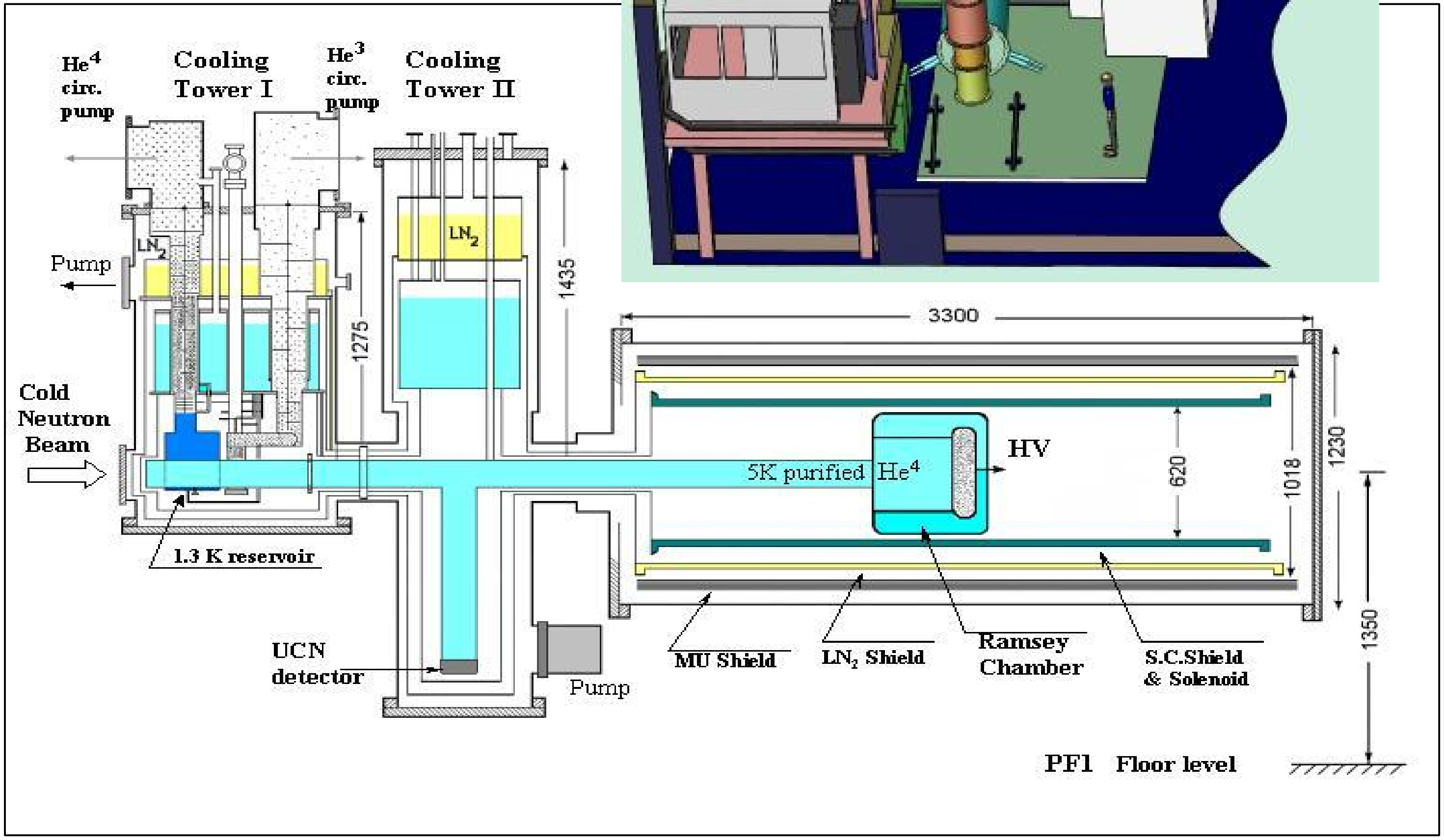


Figure 4 – Dispersion curves, see text.

A new method for the production of UCN with the potential to reach far higher densities than available from the ILL neutron turbine was first proposed in 1977 by Bob Golub and one of us (JMP). This method relies on the properties of superfluid liquid helium (sLHe), specifically, on the dispersion curve as shown in Figure 4. This plots the energy vs. the momentum for a free neutron (the red curve), which is of course just a parabola, and the energy vs. momentum for phonon excitations in the LHe (the blue curve). The properties of superfluid LHe are such that these two curves cross at a momentum corresponding to a UCN wavelength of 8.9Å. A

A dedicated UCN source for cryoEDM at ILL

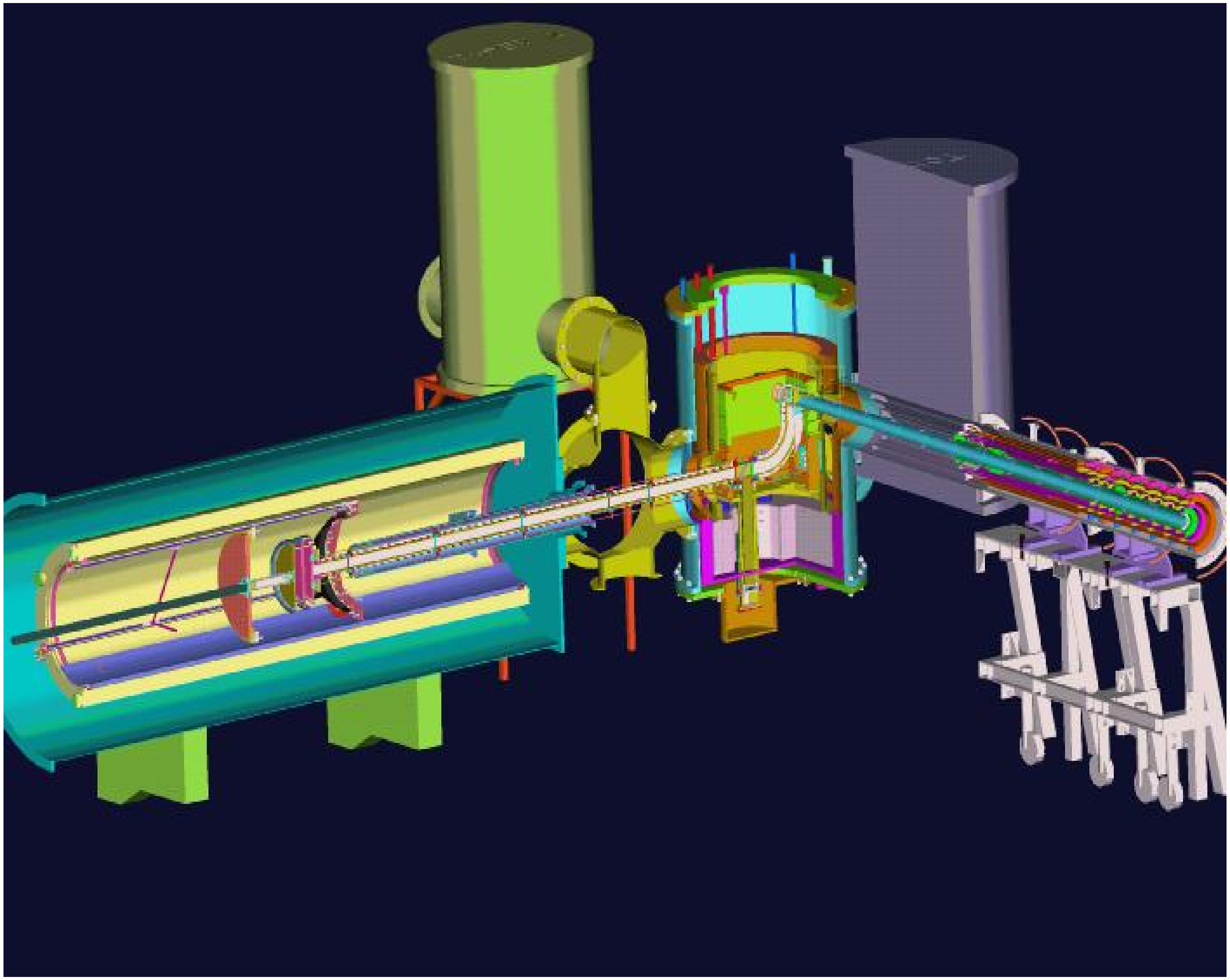




cryoEDM apparatus as planned for the ILL

A CAD overview of the apparatus as now planned for the ILL.

On the right is Cooling Tower II, which supplies superfluid LHe to the entire neutron volume, over Phase I of the new cryostat construction. On the left are the large magnetic shields surround the Ramsey cell, behind which is Cooling Tower I which supplies the cooling power to the shields. Next to Tower I is Phase II of the cryostat, which contains the UCN transfer section and the vertical detector section. Between the shields and Phase II is the 6-way cryogenic section needed for access and construction and in which we will mount the SQUIDs



Calculating the UCN density in the super-fluid ^{4}He

The UCN production rate per unit volume = (4.55 ±0.25) $\times 10^{-8}$ $(d\Phi/d\lambda)$ at 8.9 Å.

C. A. Baker et al, NIM A, 308 (2003) 67.

Thus, for $(d\Phi/d\lambda)$ at 8.9 Å = 2.5 $\times 10^{+8}$ /cm^2/s/Å,

the production rate in the superfluid is 11 UCN/cm^3/s.

If the UCN mean survival time in the super-fluid is **150 s**,

then, after having the cold beam on for **150 s**,

the UCN density will be $11 \times 150 \times (1 - e^{-1})$ = **1080 /cm^3**

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