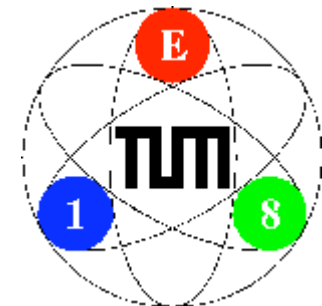# The Ultra-Cold Neutron Laboratory at the FRM-II

TRTR & IGORR Joint Meeting 2010
Knoxville, TN, USA

Dr. Andreas Frei
Physics Department - Technical University Munich (TUM)
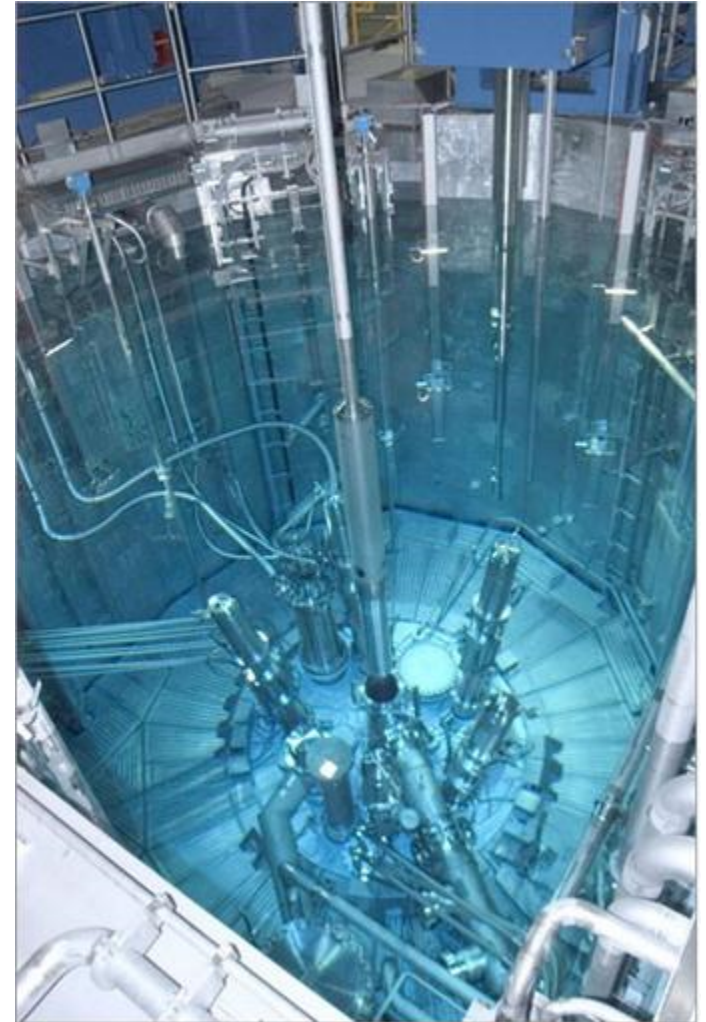Prof. Dr. Winfried Petry (FRM-II), Prof. Dr. Stephan Paul (ExC), Rainer Stoepler (TUM)

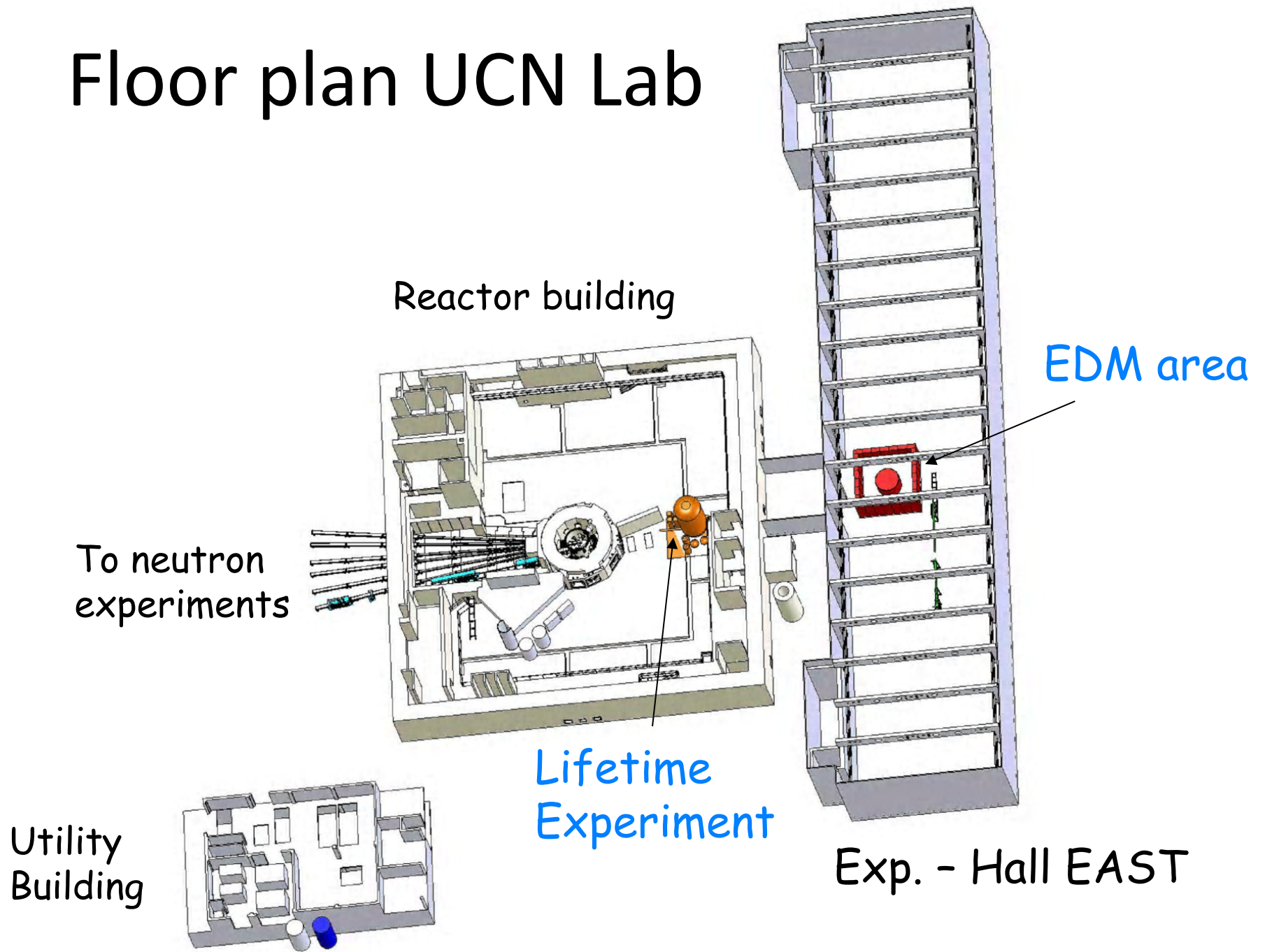# 20 MW High Flux Reactor at Garching FRM-II
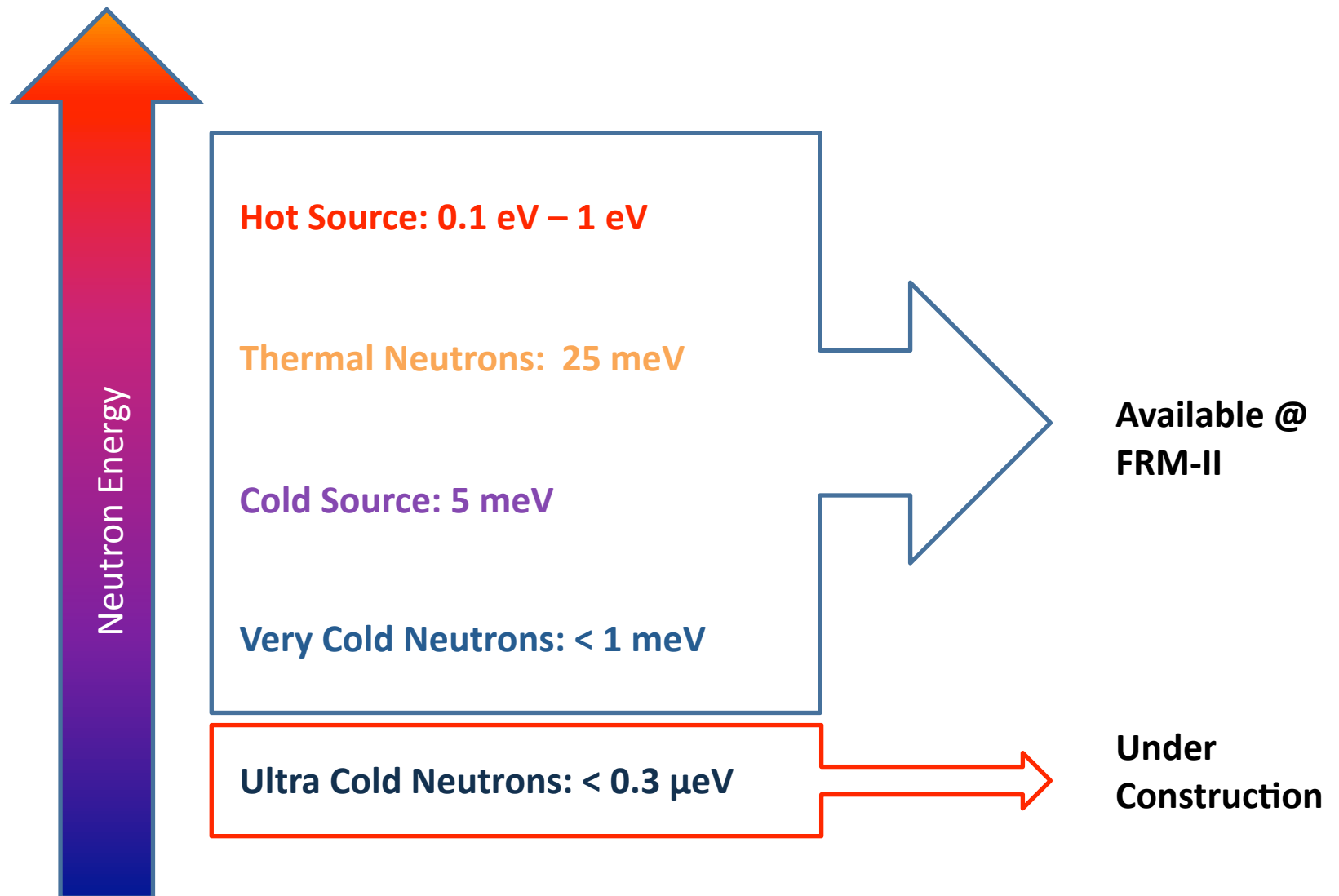

East hall   Main building   Neutron guide hall

Floor plan UCN Lab

Reactor building

To neutron experiments

EDM area

Lifetime Experiment

Utility Building

Exp. – Hall EAST

Secondary neutron sources

Neutron Energy

Hot Source: 0.1 eV – 1 eV

Thermal Neutrons: 25 meV

Cold Source: 5 meV

Very Cold Neutrons: < 1 meV

Available @ FRM-II

Ultra Cold Neutrons: < 0.3 µeV

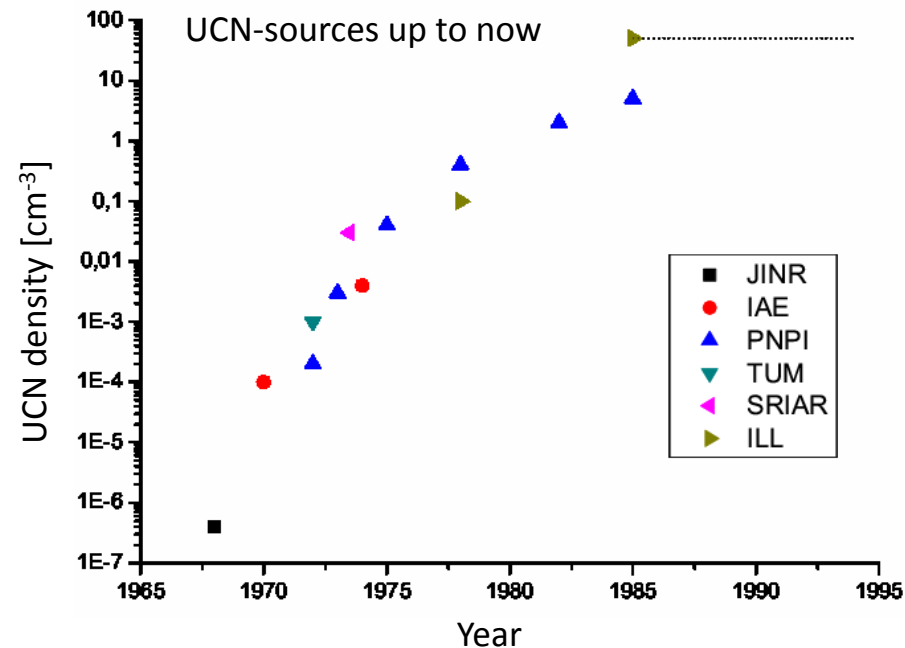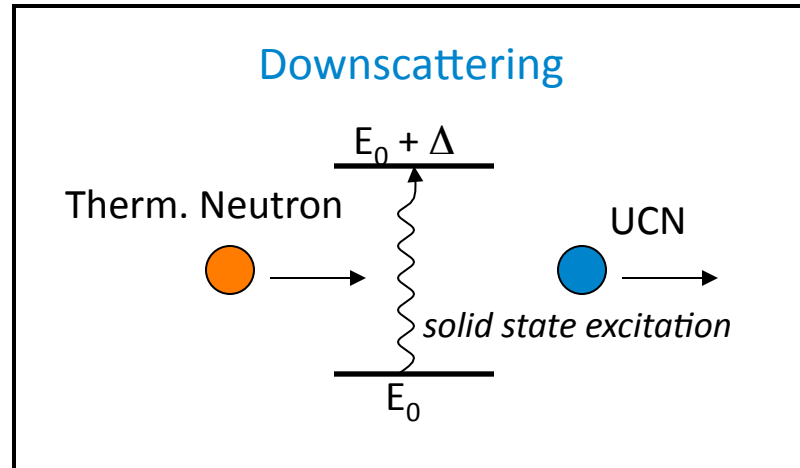Under Construction

Ultra-Cold Neutrons

- Definition: neutrons reflected from material walls → Fermi potential
- Energy: < 300 neV
- Amount: small fraction of thermal energy spectrum (~ $7 \cdot 10^{-12}$ ϕ_0 @ 300 K)
- Production: shift energy spectrum to lower energies → moderation
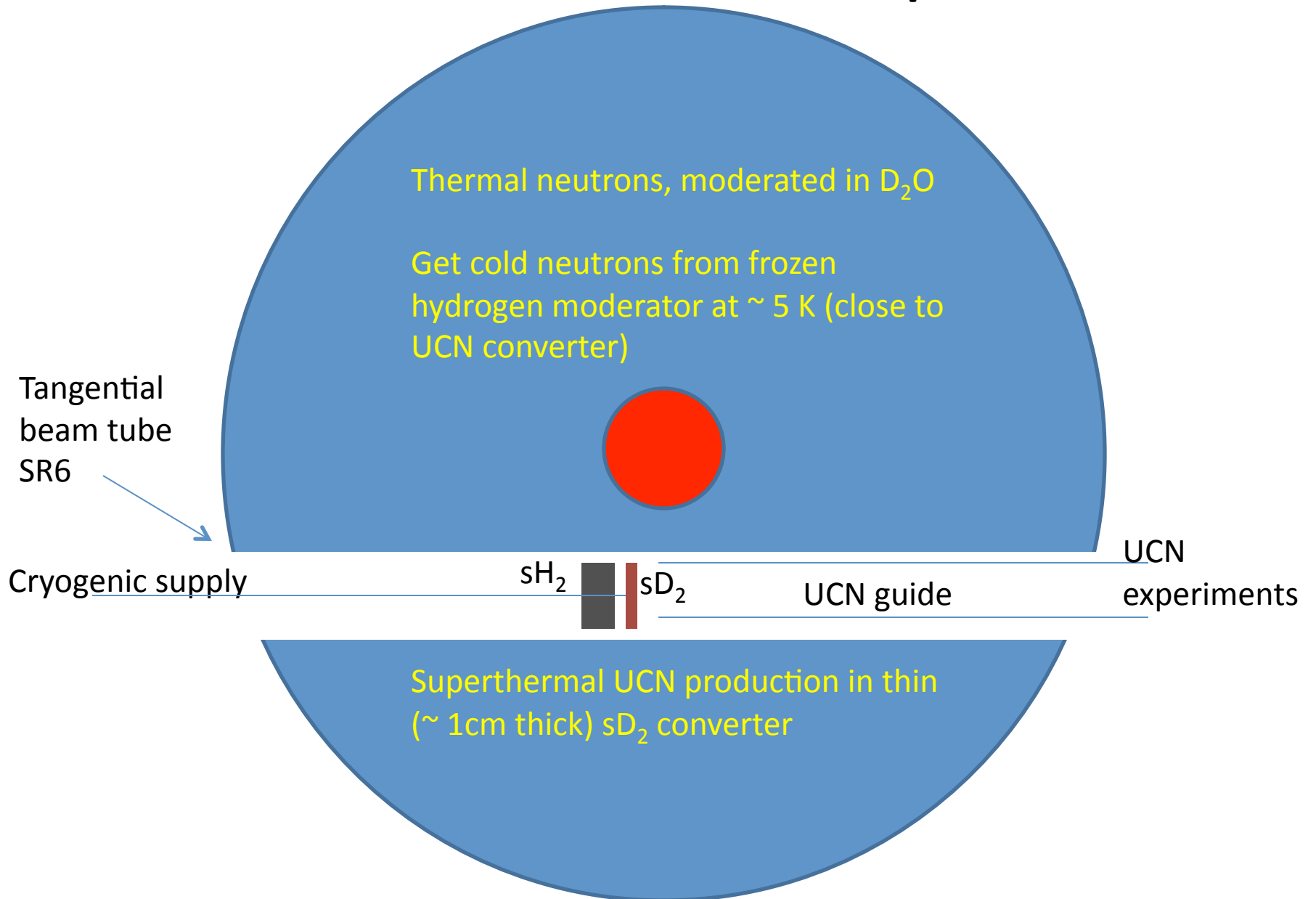
Superthermal UCN-production

- Production: $E_{UCN} + \Delta \rightarrow E_{UCN}$ (Downscattering)
- Loss: $E_{UCN} \rightarrow E_{UCN} + \Delta$ (Upscattering)
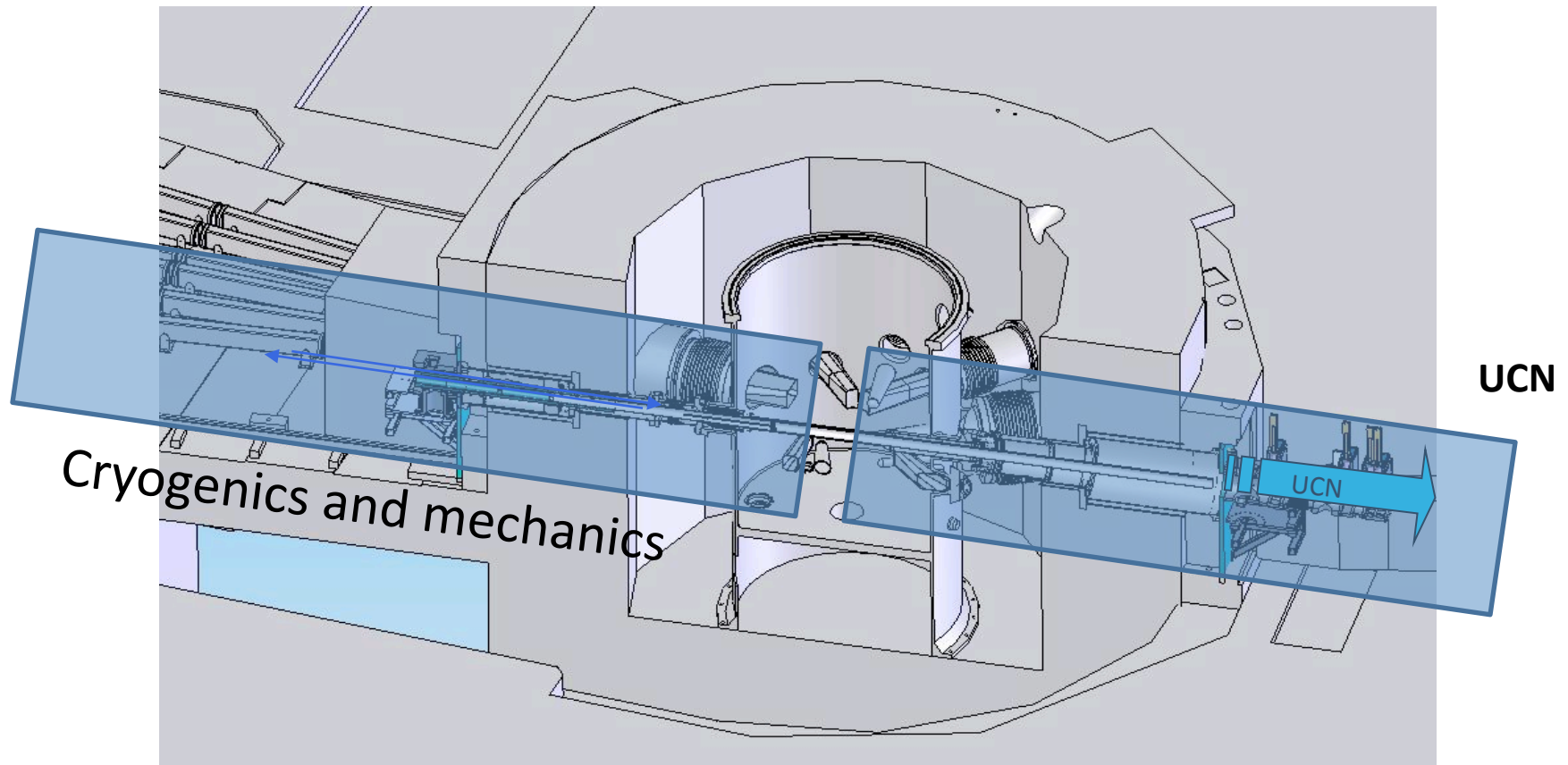
Principle of detailed balance:
$$\sigma_{up} = \frac{E_{UCN} + \Delta}{E_{UCN}} \cdot e^{-\Delta/k_B T} \cdot \sigma_{down}$$

if $\Delta \gg k_B T \gg E_{UCN} \rightarrow \sigma_{upscattering} \ll \sigma_{downscattering} \rightarrow$ **Superthermal Converter**

UCN source concept

Thermal neutrons, moderated in D_2O

Get cold neutrons from frozen hydrogen moderator at ~ 5 K (close to UCN converter)

Tangential beam tube SR6

Cryogenic supply

sH$_2$

sD$_2$

UCN guide

UCN experiments

Superthermal UCN production in thin (~ 1cm thick) sD$_2$ converter

Cut through reactor

Cryogenics and mechanics

UCN

More details

Mini-D₂ @ FRMII SR6
ReactorCore
UCN
Cryogenic Supply
UCN Converter Cell

Reactor Core

Biological Shield (Concrete)

D_2O

H_2O

Plug

Plug

Supply Lines (He, H_2, D_2)

UCN Converter

UCN Guide

Solid-D$_2$ UCN-Converter

Design of the sD$_2$ Converter

In-pile tube = UCN guide

5 K He-cooling

D$_2$ frozen to surface

H$_2$ pre-moderator

- H$_2$-amount: 12.5 mol   = 25 g
- D$_2$-amount: 12.5 mol   = 50 g
- He-amount: 70 dm^3 fl.-He   = 8.7 kg

Source design

Solid H$_2$ container

Solid D$_2$ surface
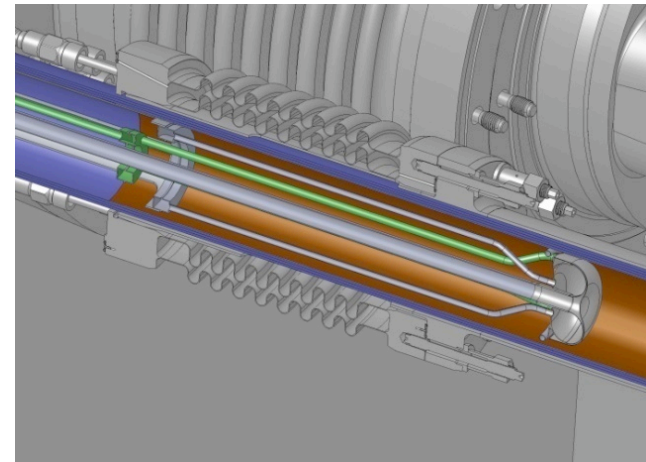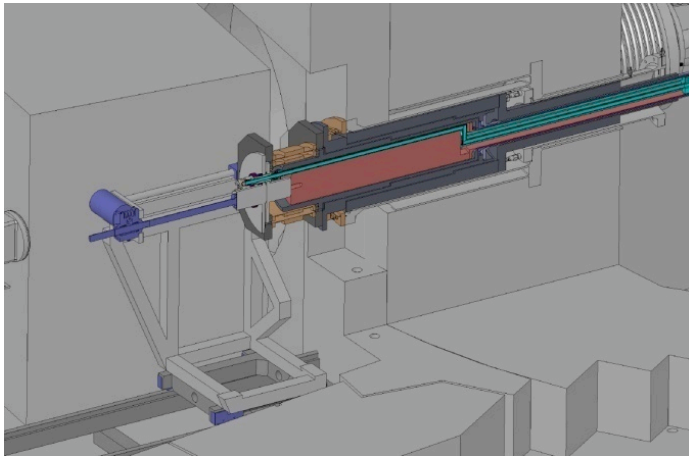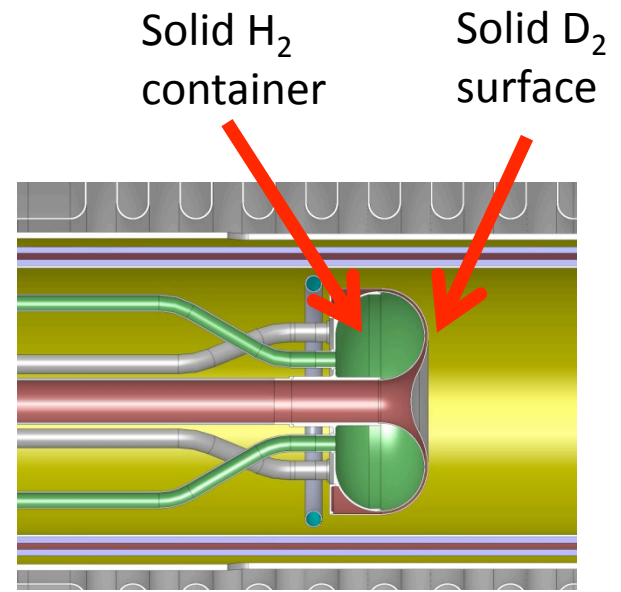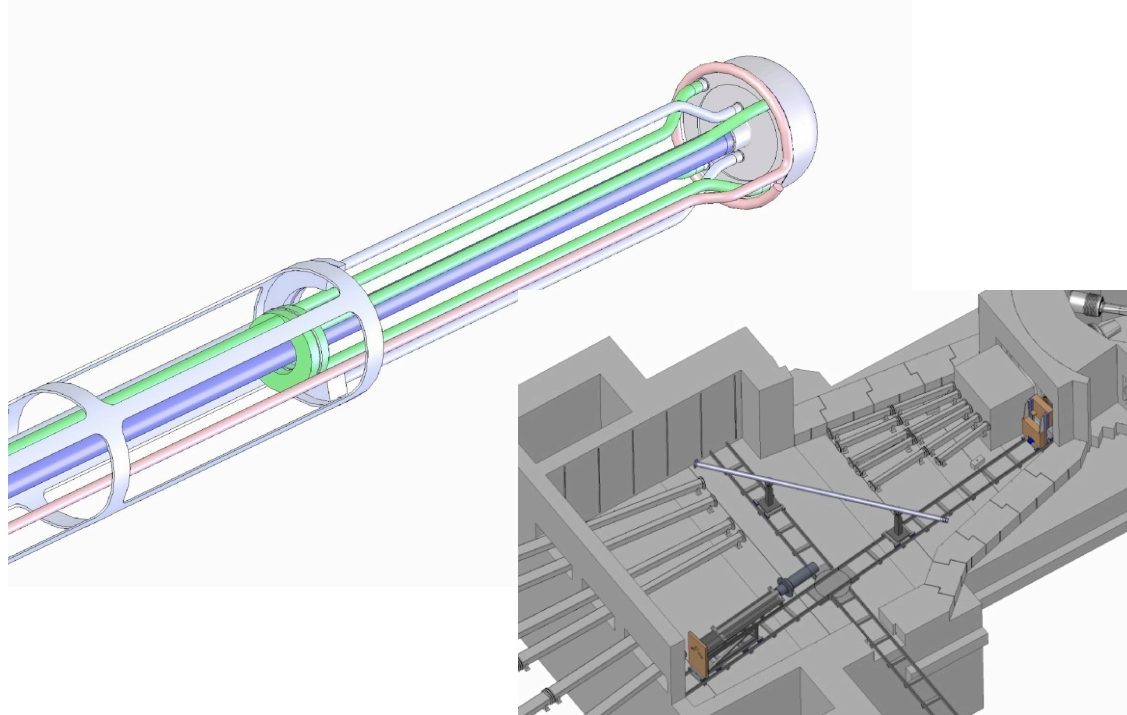
Cooling concept

Cooling He velocity profile
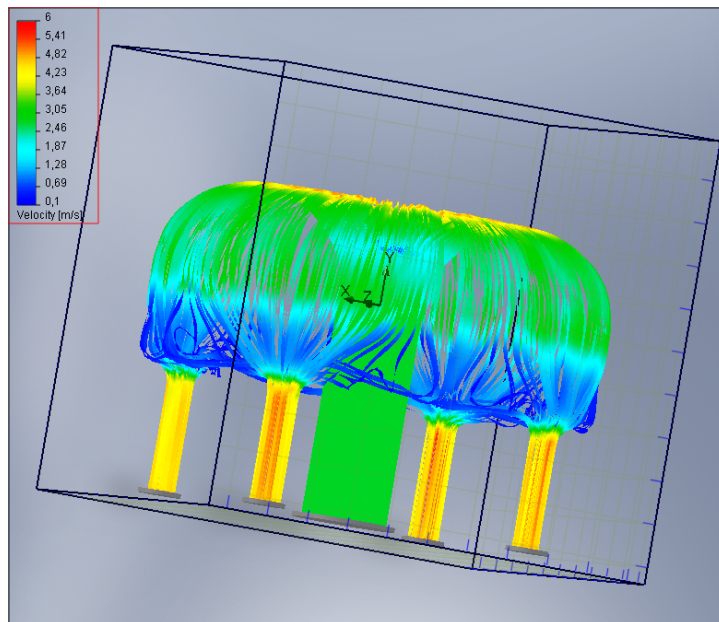
Nuclear heating:

Al - 1.8 W/cm^3
D$_2$ - 0.09 W/cm^3
H$_2$ - 0.05 W/cm^3

Total cooling power 500 W @4.2K

He mass flow	100 g/s
He pressure	3 bar
Pressure drop	0.09 bar
Temperature increase	0.2 K
Heat transfer coeff.	500 W/cm^2/K

Successful cooldown

Functional prototype welded.
Survived pressure and leak testing,
tested at < 10 K, neon frozen out.
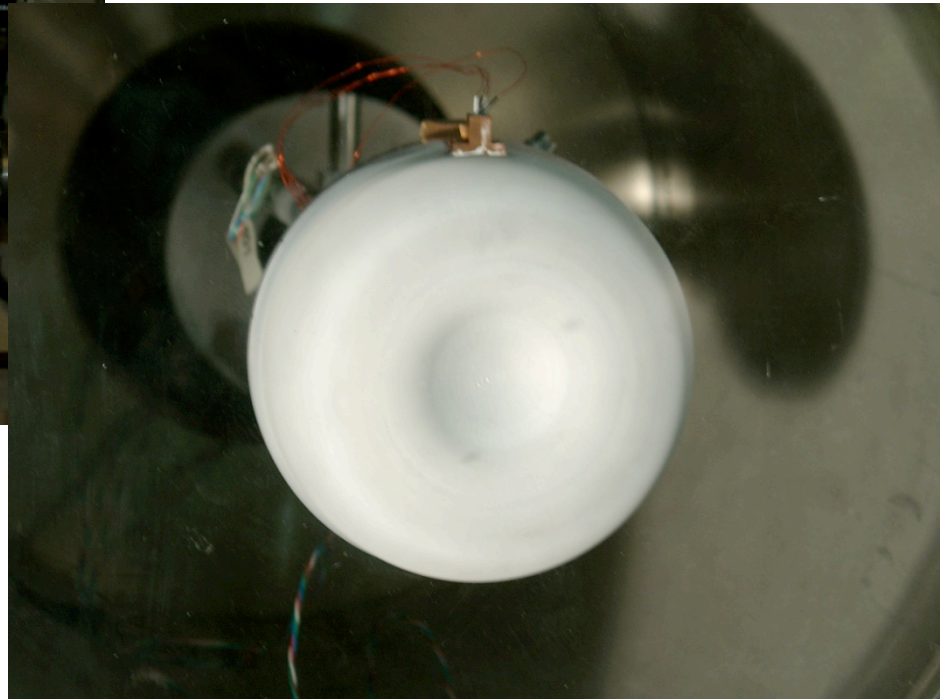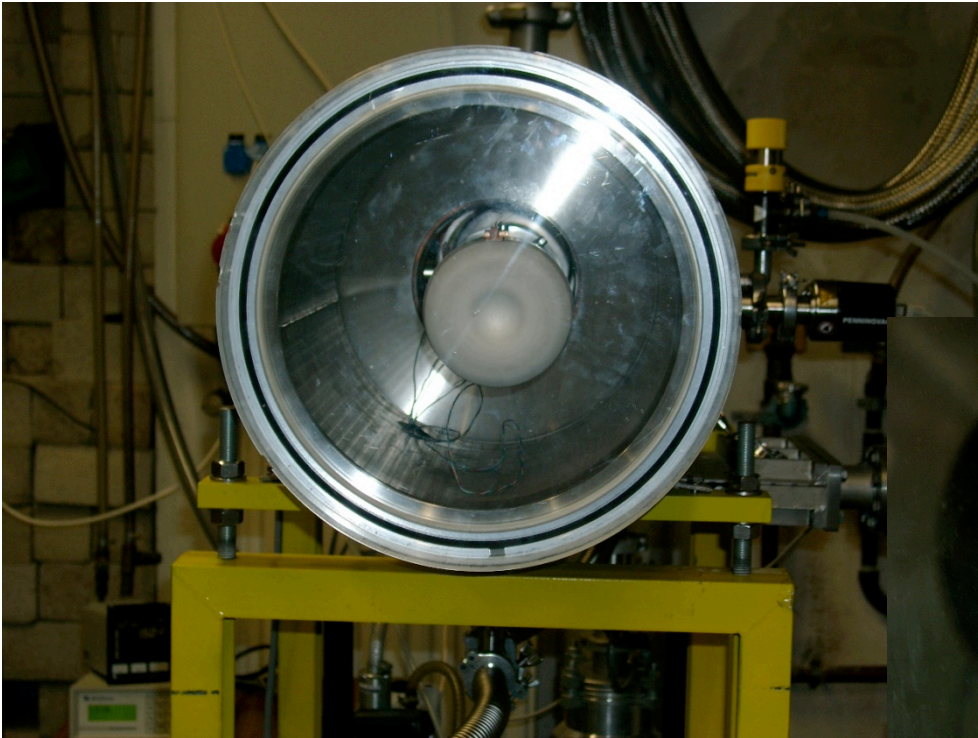
Cooling efficiency

Solid D_2 temperature profile
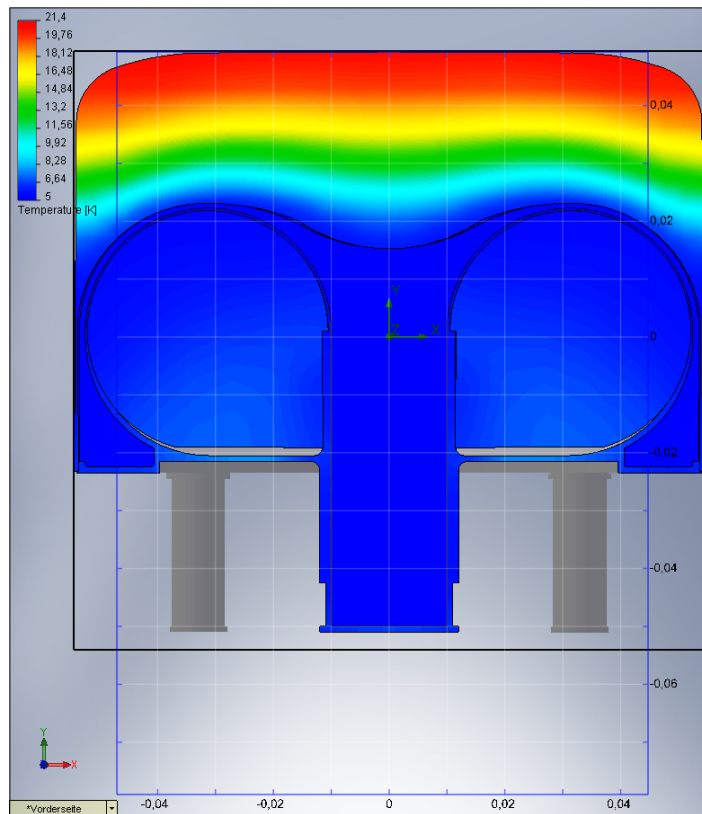
Extreme case with 3 cm thick D_2 and 100% increased heating

~1 cm of o-D_2
are feasible to have vapor pressure at the level of 10^{-3} mbar

Neutron optics

Problem: a very long UCN guide…

Goal: Transmission > 0.985/m

Ni surface copied from glass
-> Replica technique

A few more pictures

Cryogenics
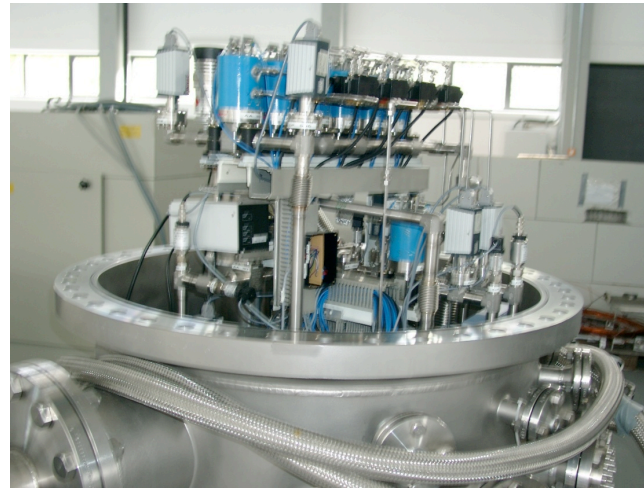
Deuterium system

Flanged access to SR6 where cryogenics will be placed

Expected performance of UCN source @ FRMII

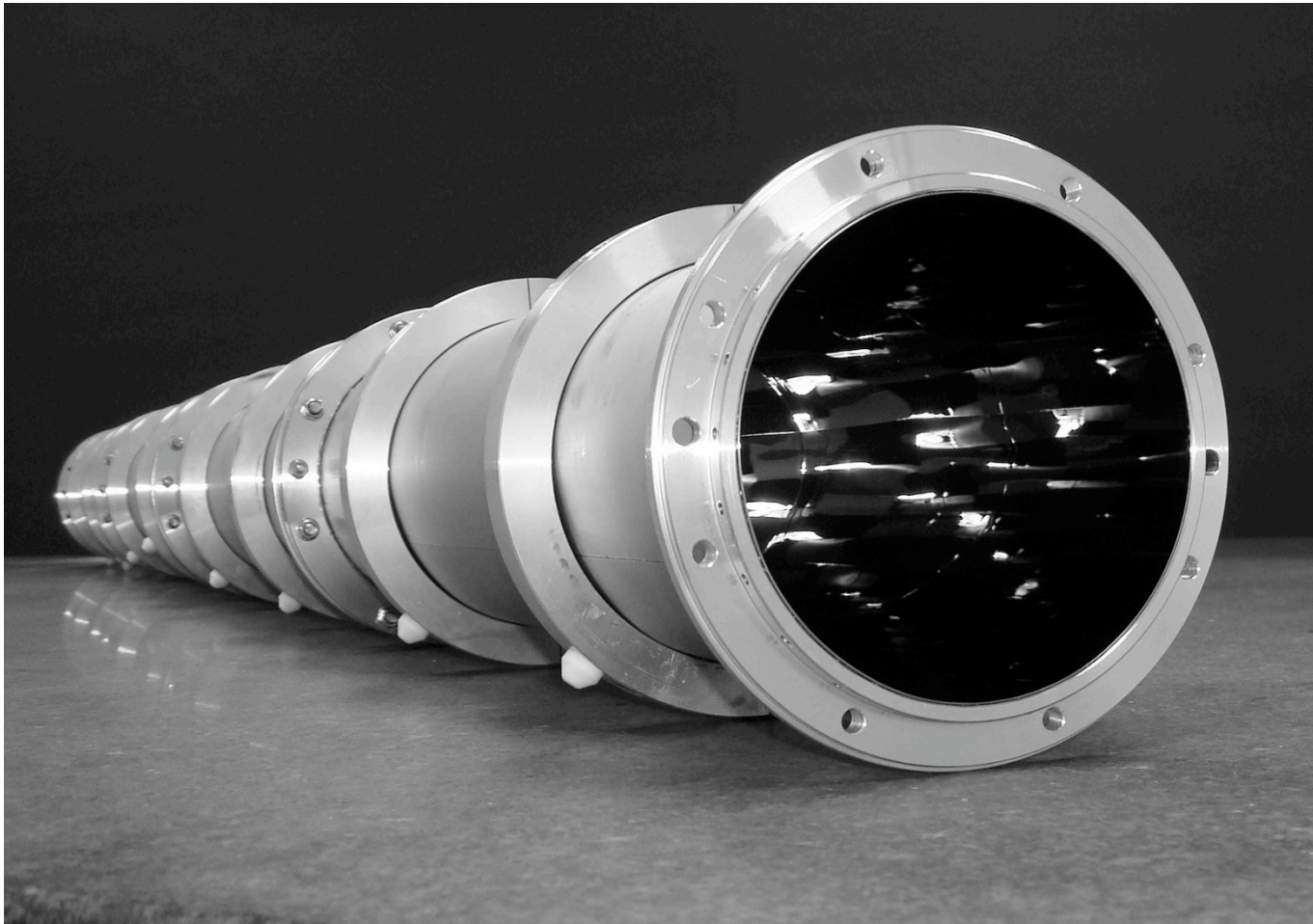|	UCN source FRMII Exit of beam port	Experiment hall PENeLOPE
Flux density [UCN · cm^{-2} · s^{-1}]	$7.0 \cdot 10^4$	$6.2 \cdot 10^4$
Flux [UCN · s^{-1}]	$8.0 \cdot 10^6$	$7.0 \cdot 10^6$
Max. UCN density [UCN · cm^{-3}]	$1.2 \cdot 10^4$ (V = 100 dm^3)	$3.0 \cdot 10^3$ (V = 700 dm^3)

Experiments with UCN

- Neutron lifetime

- Neutron Electric Dipole Moment

- Gravitational quantum states of UCN

- Monochromatic pulsed neutron beams by UCN upscattering

- UCN guide development

- Alternative UCN converter materials
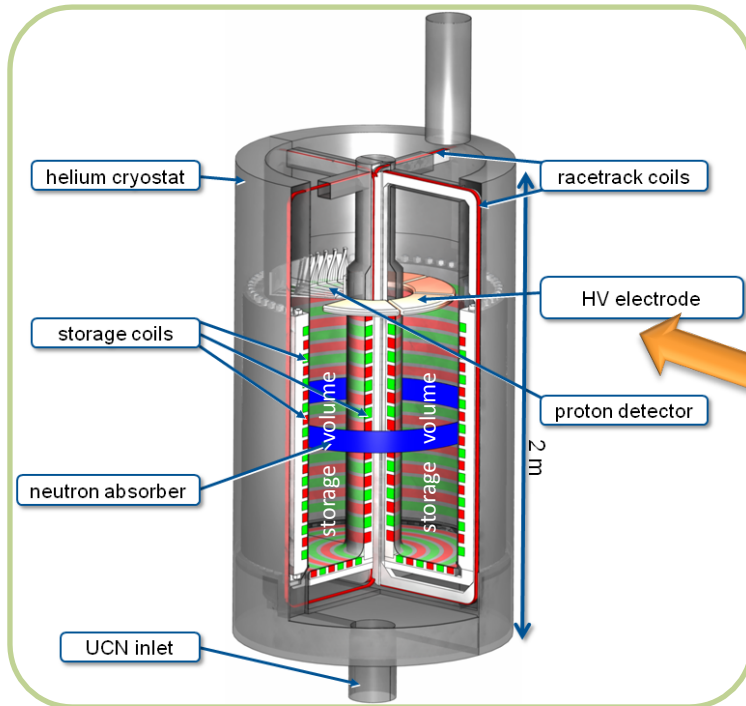
- …

Neutron lifetime: PENeLOPE

a **P**recision **E**xperiment on the **N**eutron **L**ifetime **O**perating with **P**roton **E**xtraction

I. Altarev, E. Gutsmiedl, F.J. Hartmann, S. Materne, J. Nitschke, S. Paul, R. Picker, T. Schäfer, R. Stoepler, C. Tietze

TU München

Labels: helium cryostat · storage coils · neutron absorber · UCN inlet · racetrack coils · HV electrode · proton detector · storage volume · 2 m
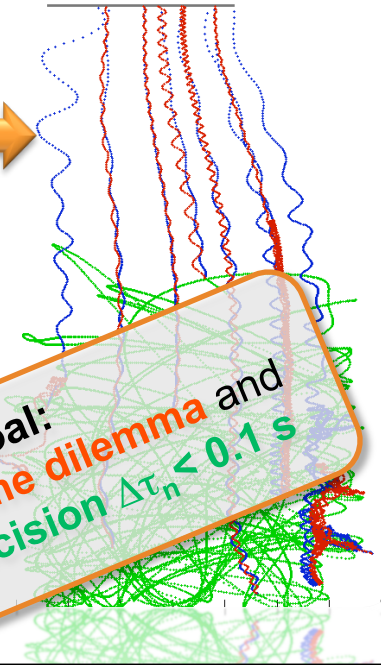
Motivation:

incompatible values of recent experiments using material neutron storage + unresolved **systematic uncertainties** of old method

PDG world average: $\tau_n = 885.7 \pm 0.8$ s

Method:

- **loss-less magnetic** and gravitational storage
- real-time **detection of protons**
- $\Rightarrow$ storage of 10^7 **neutrons** < 110 neV in volume of around 750 l

detector

Minimization or control of **systematic effects**:

- avoid **zero-field regions (spin flip)**
- **monitoring of depolarized** UCN
- shaping of magnetic storage-field
- **removal of marginally trapped UCN**
- …

Goal: resolve **lifetime dilemma** and achieve **precision** $\Delta\tau_n < 0.1$ s

neutron, **proton** and **electron** tracks in PENeLOPE

TUM

LMU

ESO

Excellence Cluster | Universe

Deutsche Forschungsgemeinschaft DFG

MLL

Bundesministerium für Bildung und Forschung

Electric Dipole Moment nEDM

Ramsey method: Measure Lamor frequency shift
with electric field $\hbar\omega \sim \mu B + dE$

Start	$\pi/2$ pulse	Precession τ	$\pi/2$ pulse	Analysis
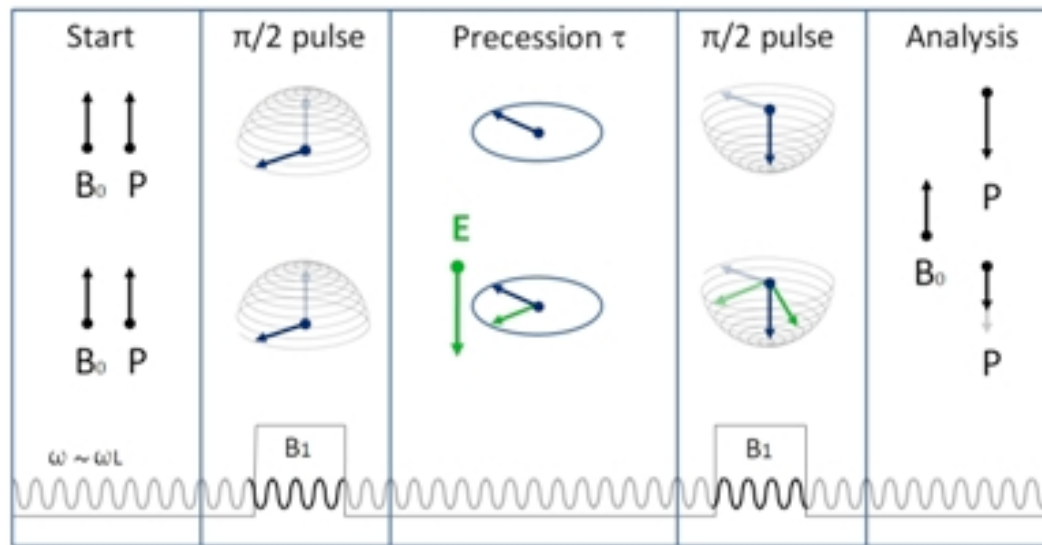
Current limit: $2.9 \cdot 10^{-26}$ ecm
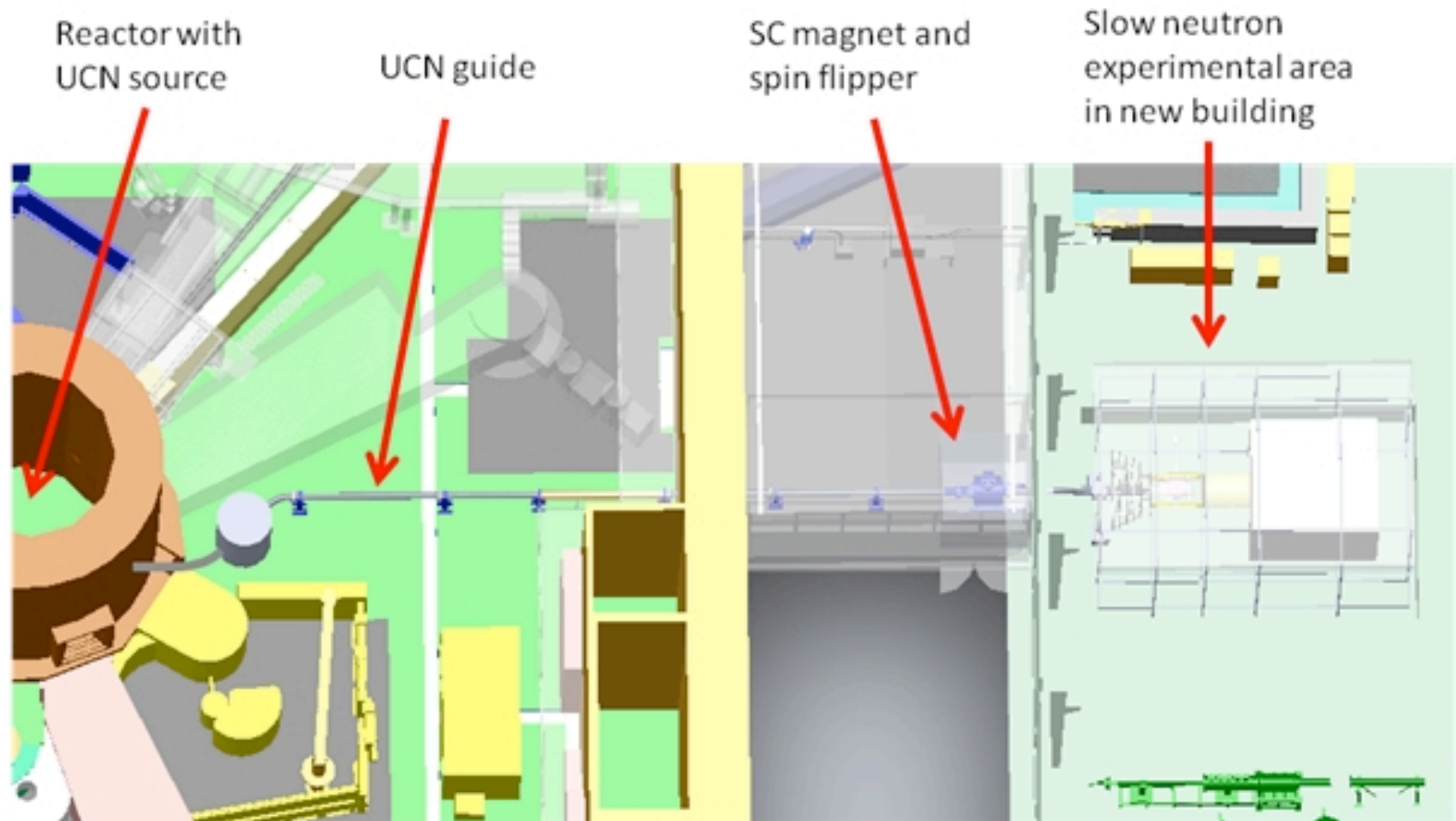Goal: $\sim 10^{-28}$ ecm (until 2015)

Sensitivity: $\sigma_d = \dfrac{\hbar}{ET\alpha\sqrt{N}}$

$\rightarrow$ strong UCN source

Problem: "fake EDM" by
fluctuations of magnetic field: $d = \dfrac{\mu\Delta B}{2E}$

$\rightarrow$ magnetic shielding

EDM floor plan

Reactor with
UCN source

UCN guide

SC magnet and
spin flipper

Slow neutron
experimental area
in new building

Conclusion

Funding secured

Design completed (inputs from prototype tests)

Cooling system ordered (3,7 M€)

Mechanics

    D_2/H_2 cup test-production

    Welding tests completed successfully

    Material ordered

    Tests for UCN guide system (almost 40m) ongoing

TÜV – papers in progress

Alternative converter material tests ongoing (basic science)

→ In 2012 this will be ‚the strongest UCN source' ☺