



Chemical and isotopic purification of hydrogen for μCap experiment

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μCap experiment

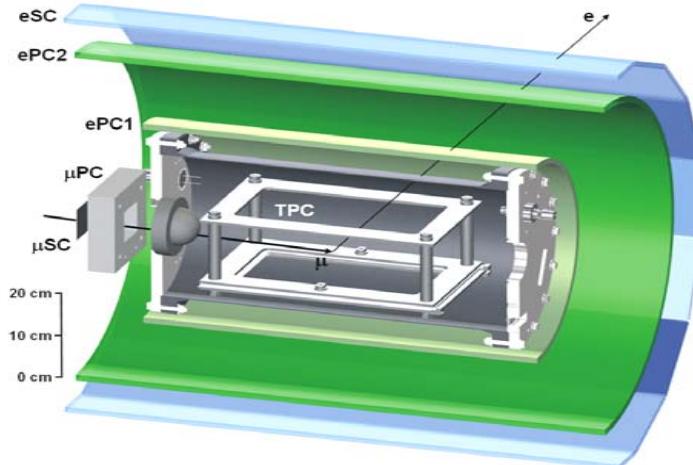
The aim of hydrogen purification.

Precision Measurement of Muon Capture on the Proton

"μCap experiment"



<http://www.npl.uiuc.edu/exp/mucapture/>



Supported by the CRDF under Award No. RP2-2414-GA-02

Deuterium depleted hydrogen gas (so called protium) must be used in MuCAP (Muon Capture on the Proton) experiment to achieve high precision measurements of the muon lifetime in the μ -p system.

The concentration of deuterium (2H/1H ratio) must not exceed 0.1 ppm.

V. A. Andreev et al., Measurement of the Muon Capture Rate in Hydrogen Gas and Determination of the Proton's Pseudoscalar Coupling , Phys. Rev. Lett. 99, 032002 (2007)



What we have to reach...

Chemical purity:

- N₂, O₂ – diffusion from the air and outgassing. 20-30 ppb.
Partial pressure 10 bar x 20·10⁻⁹= 2·10⁻⁴ mbar
- H₂O – from everywhere. 20-30 ppb.

Isotopic purity:

- HD molecules 100-200 ppb.



Reasons for Circulation system?

- constant flux is necessary for the permanent gas purification.
about 3 l/min
- price of pure hydrogen is essential.
about 1000 Eur/m³
- stable pressure in TPC is important.
10 bar +/- 0.1% (10 mbar)

Type of compressor? Normal or Cryo-?

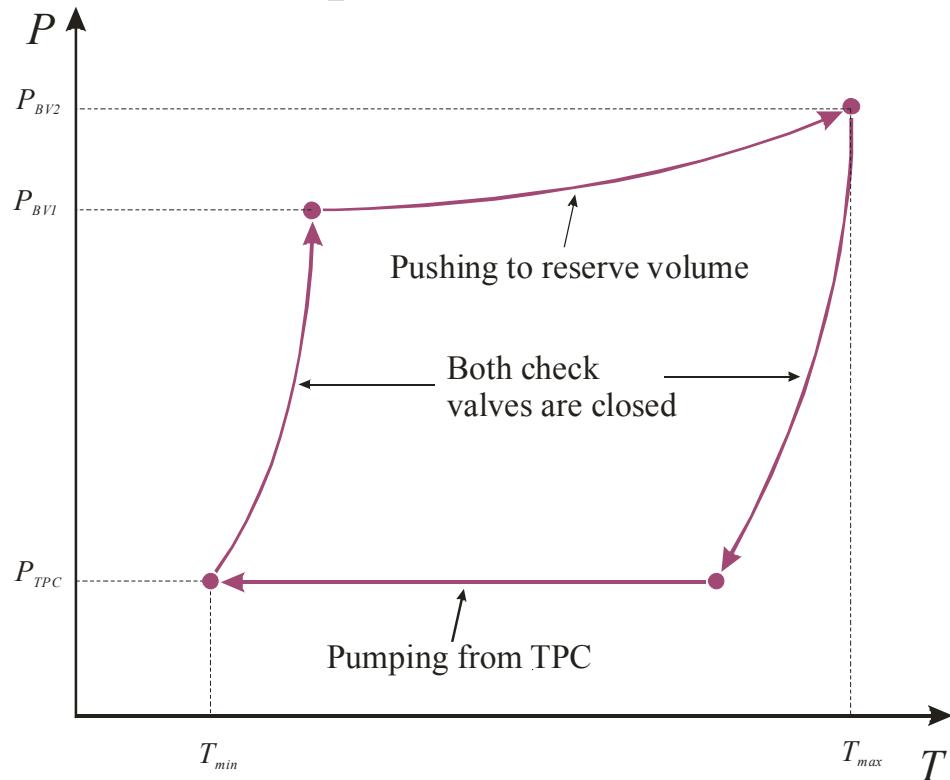
10 bar absolute pressure
3 bar differential pressure
3-4 l/min flux
ultra pure!!!

We did not find commercial compressors...

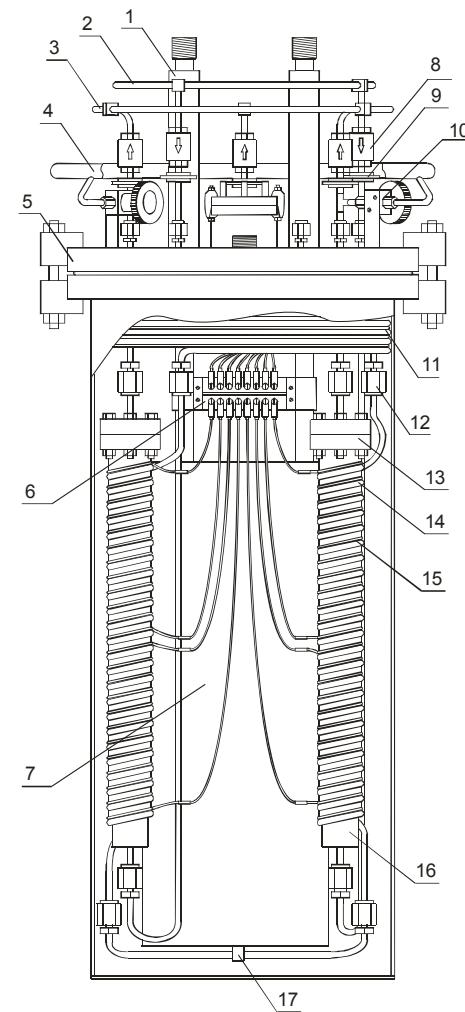
Homemade cryo-!



Simplified P-T diagram of a Compressor column

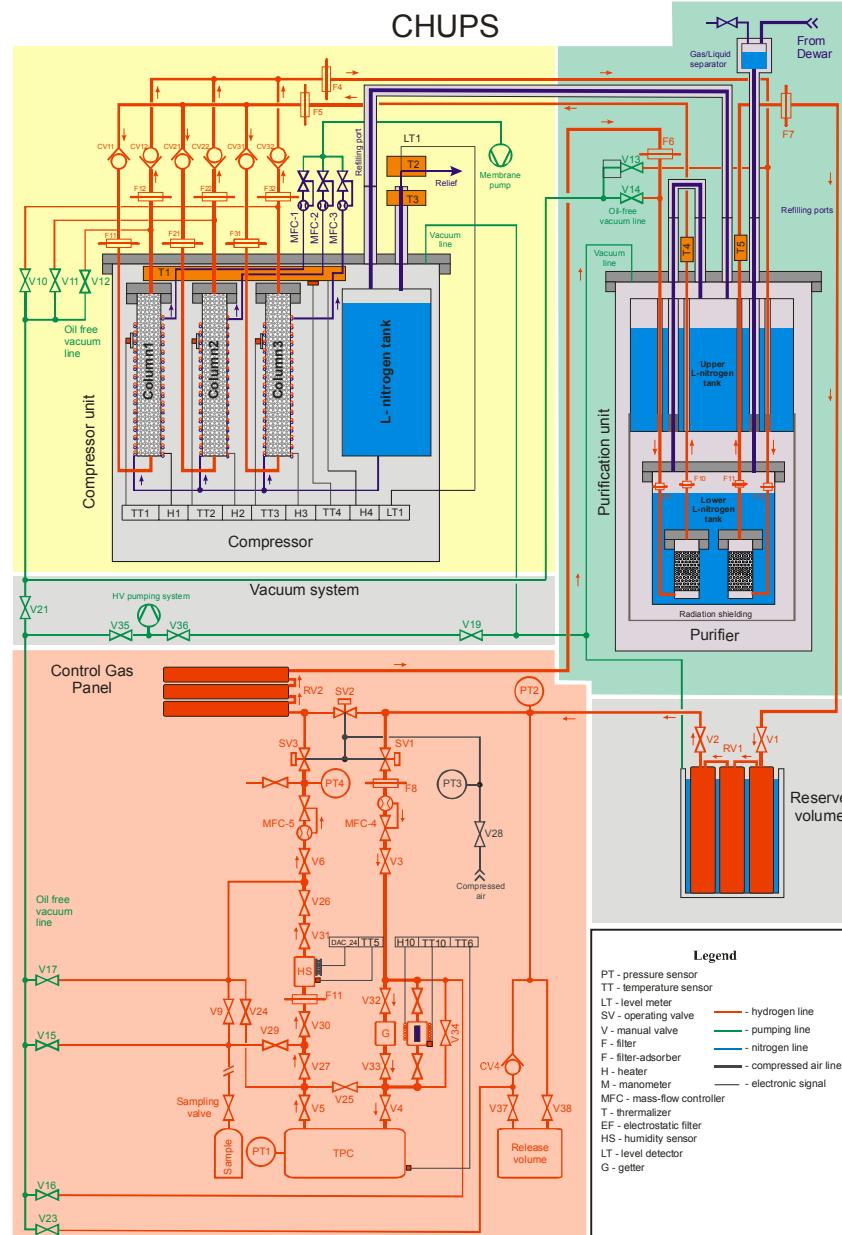


Compressor block





CHUPS scheme





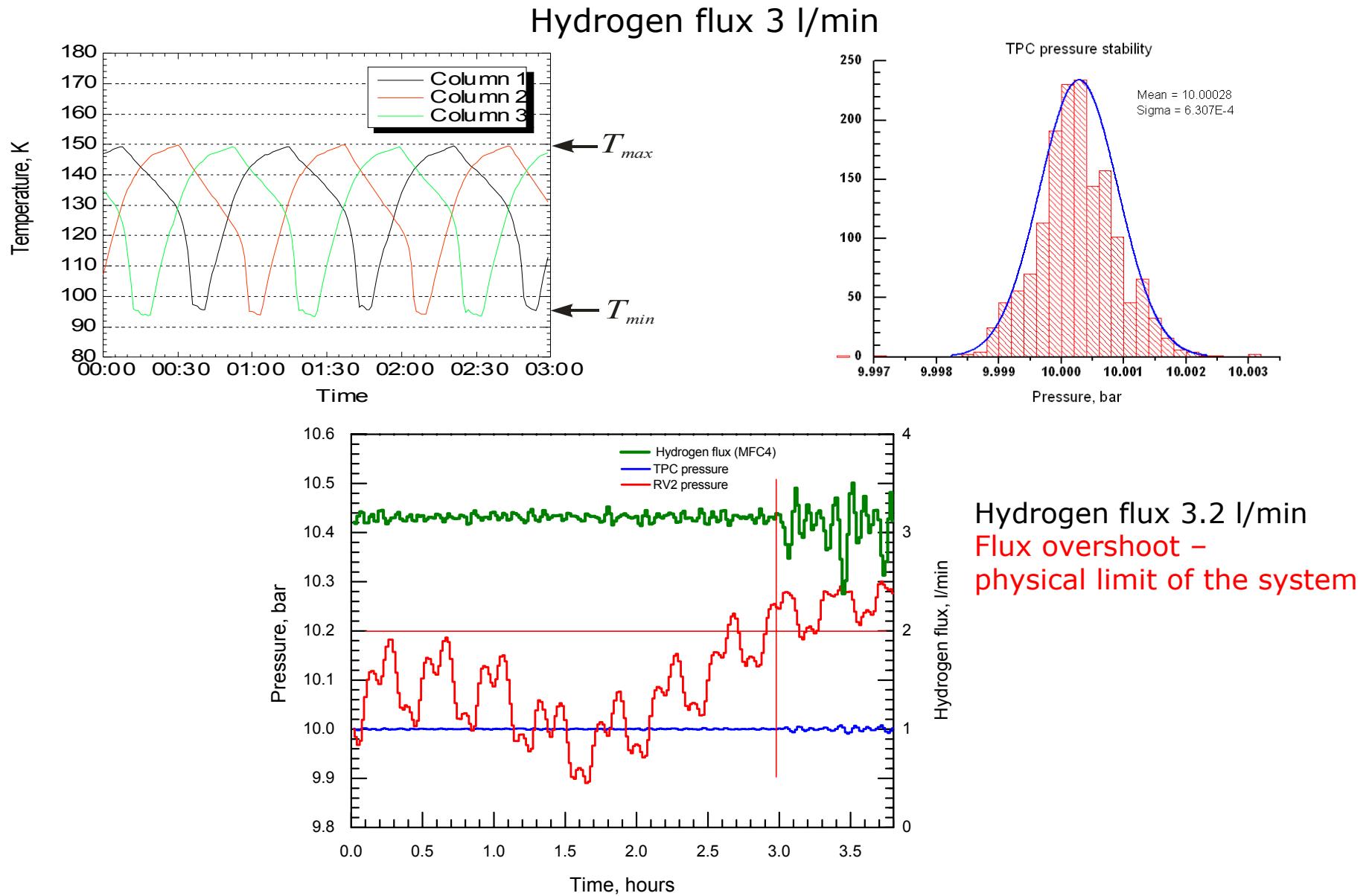
CHUPS



26.05.2008

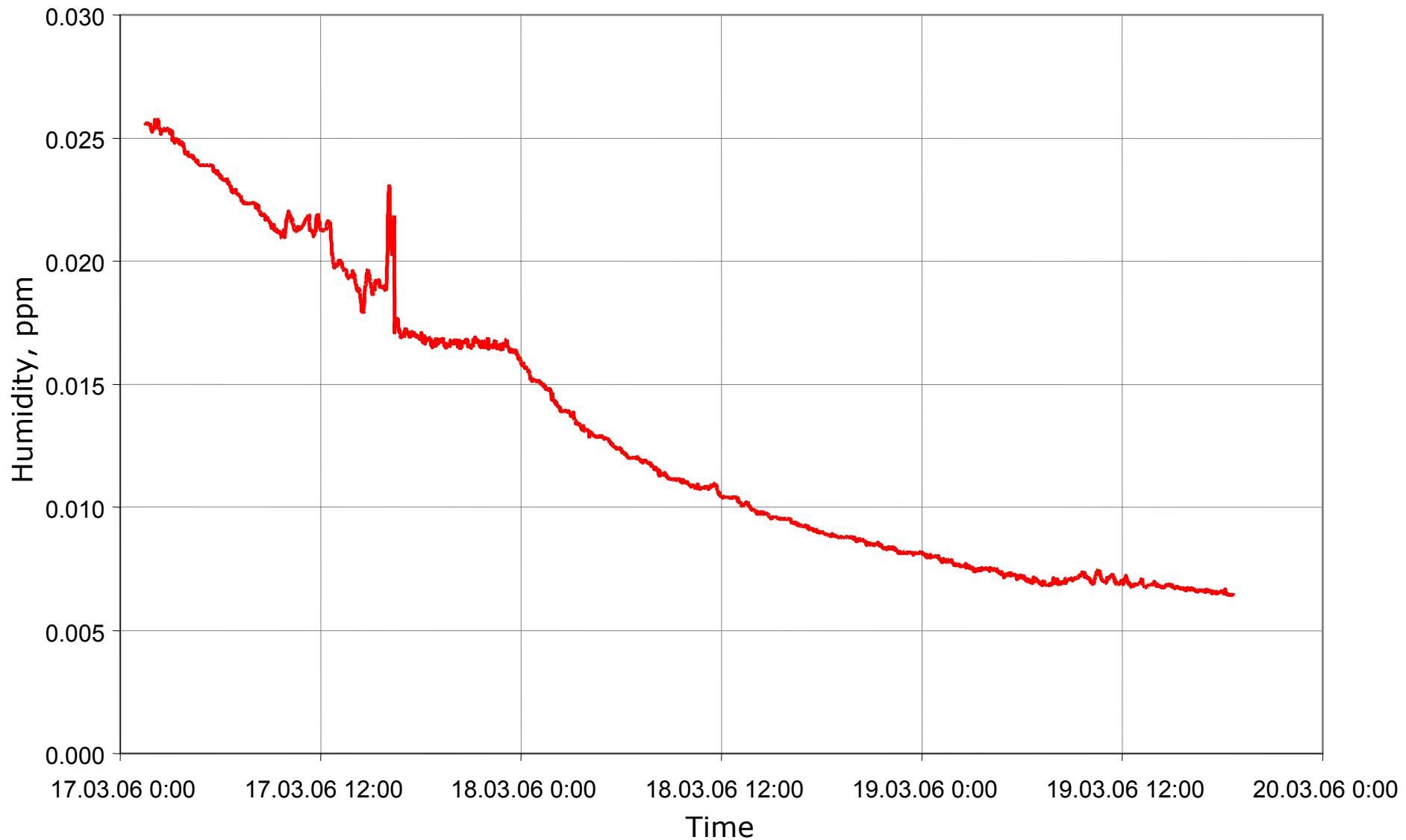
Alexander Vasilyev

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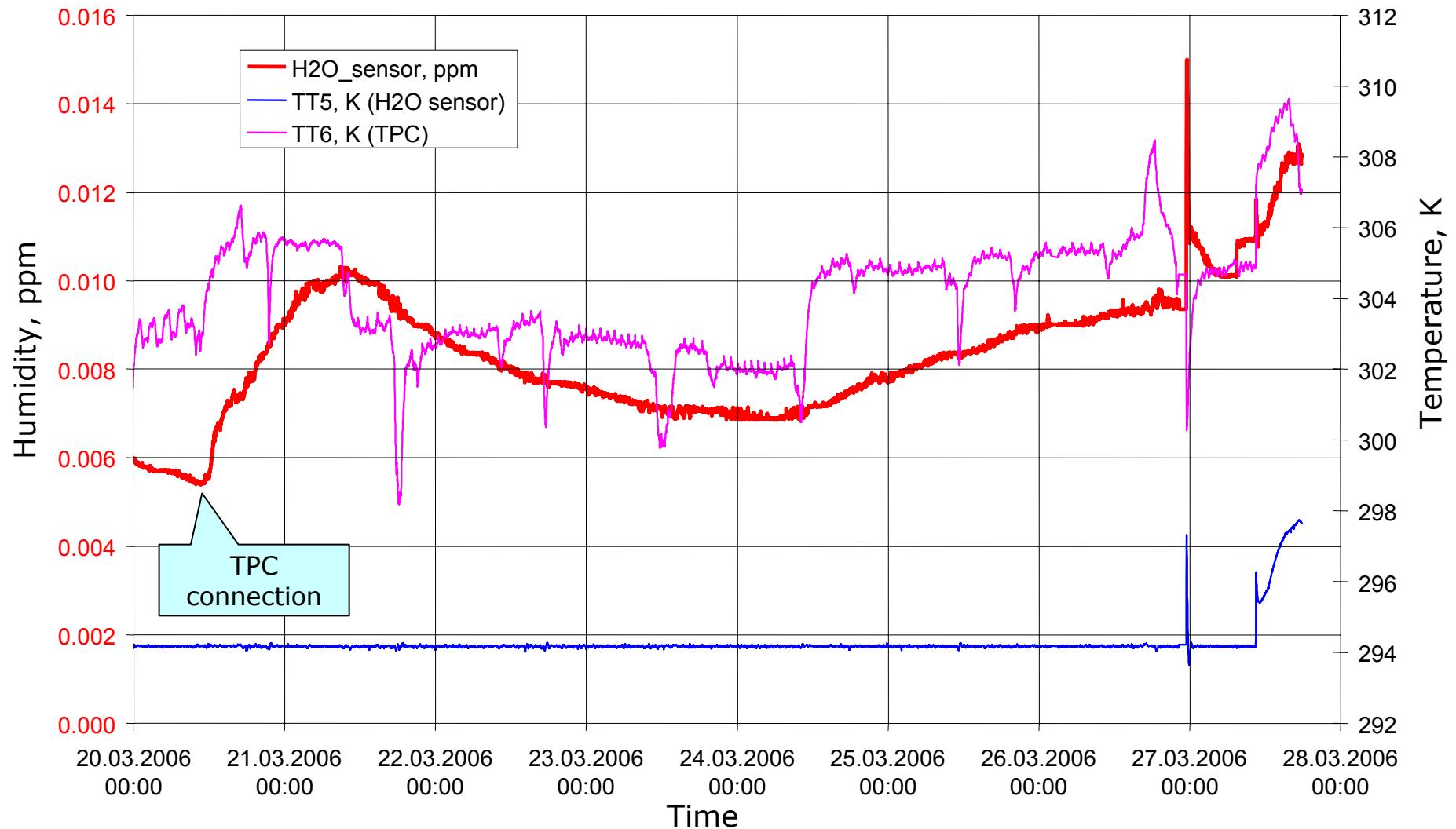


Moisture measurements in CHUPS without TPC



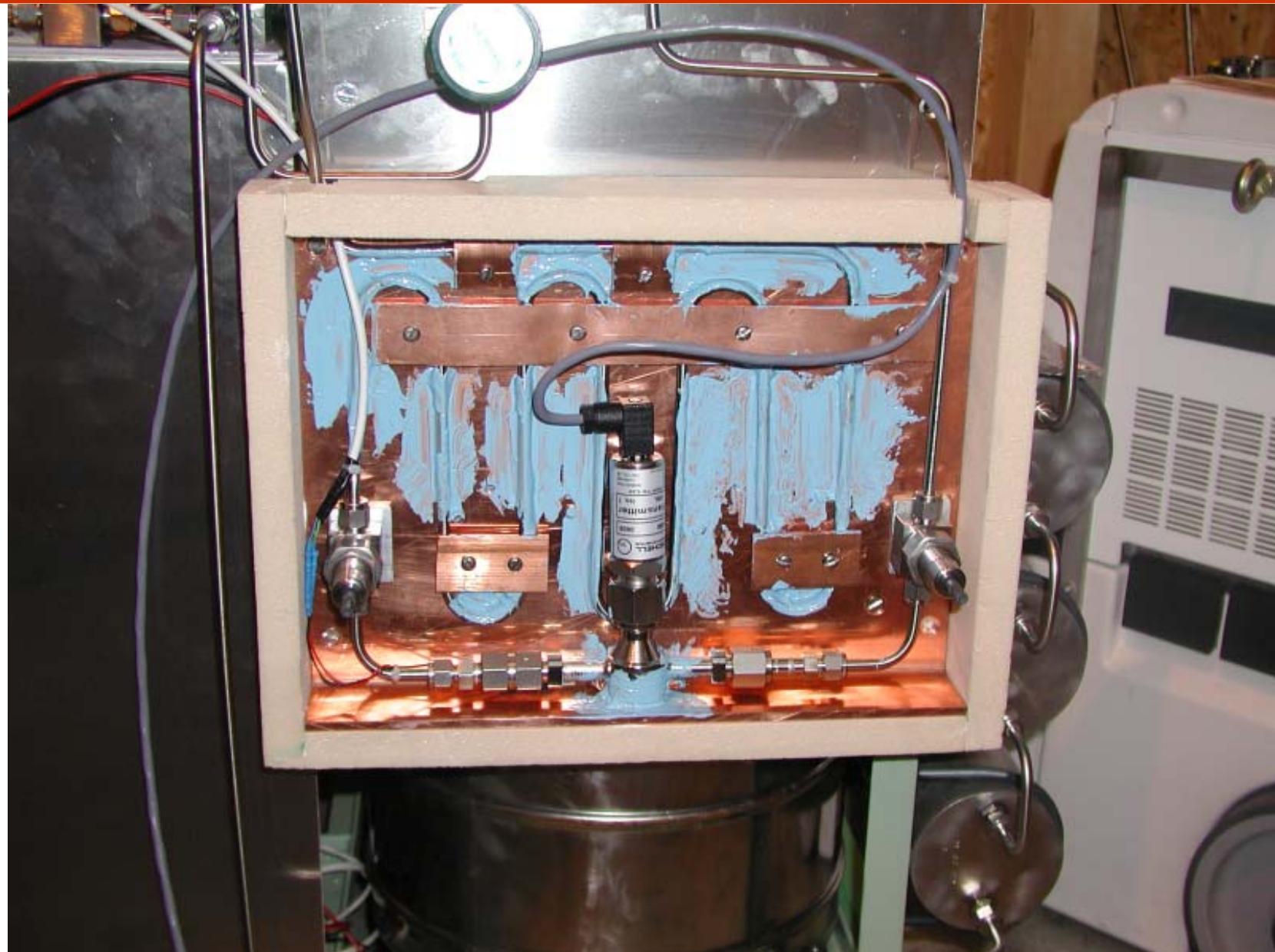


Moisture measurements in CHUPS with TPC



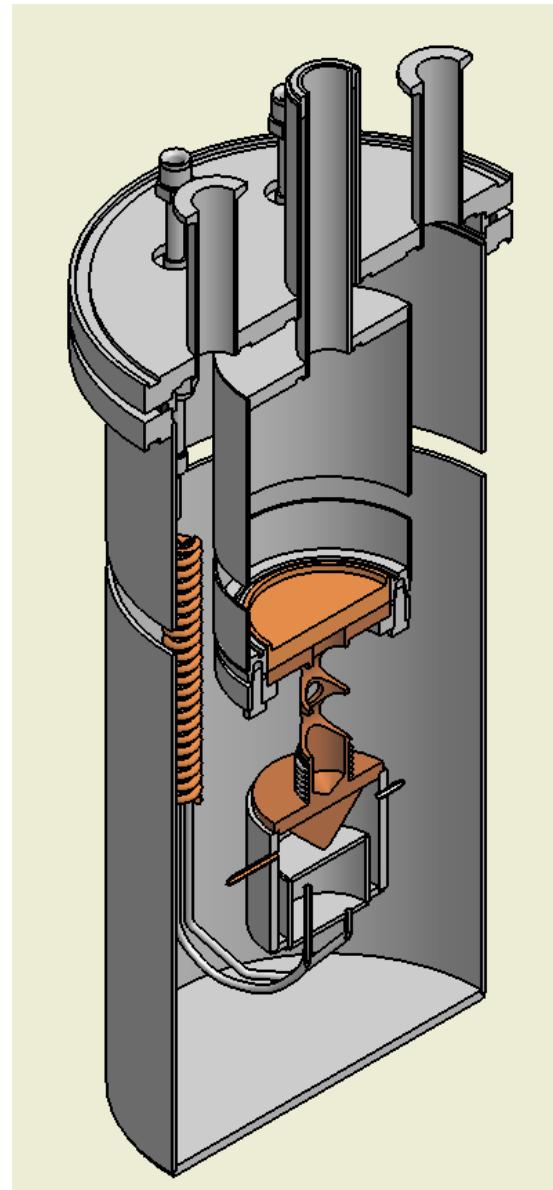


Humidity sensor (HS) and its temperature stabilization system





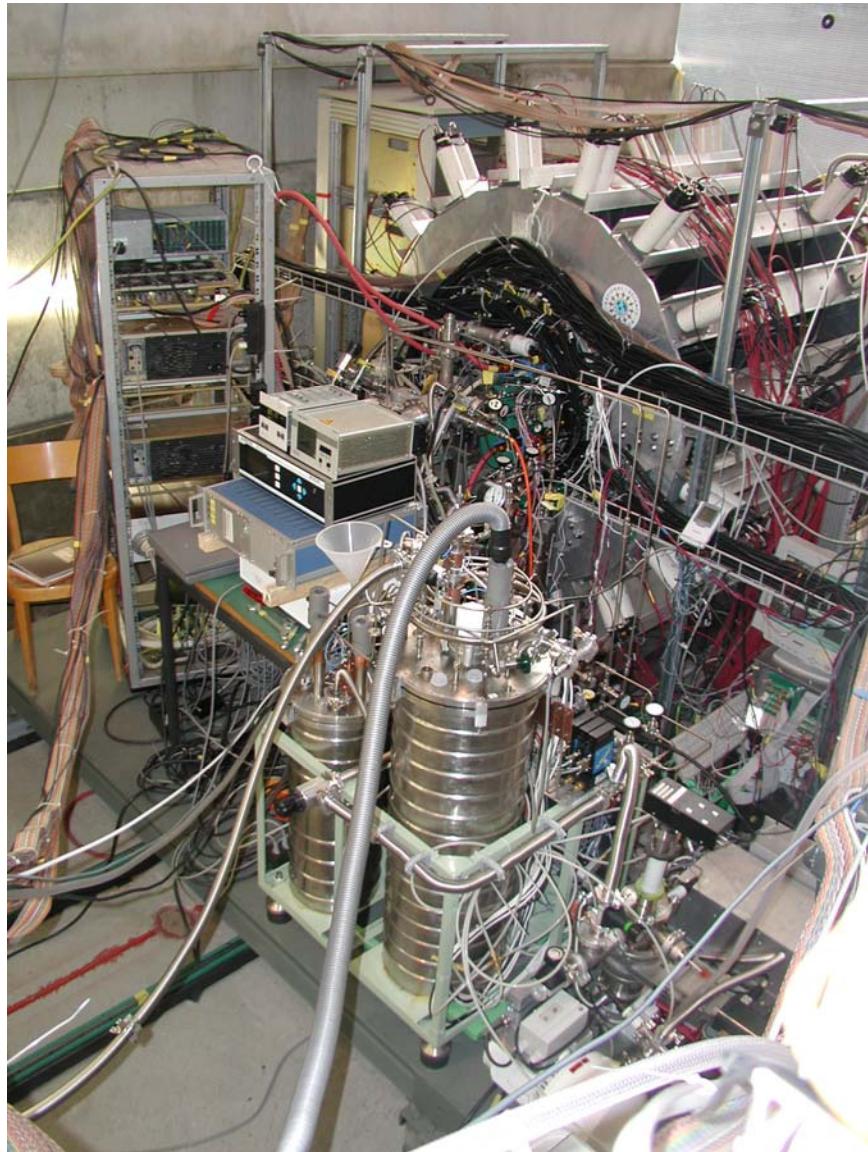
Humidity calibration





CHUPS results

N₂ less than 5-7 ppb
O₂ less than 5 ppb
H₂O about 15 ppb





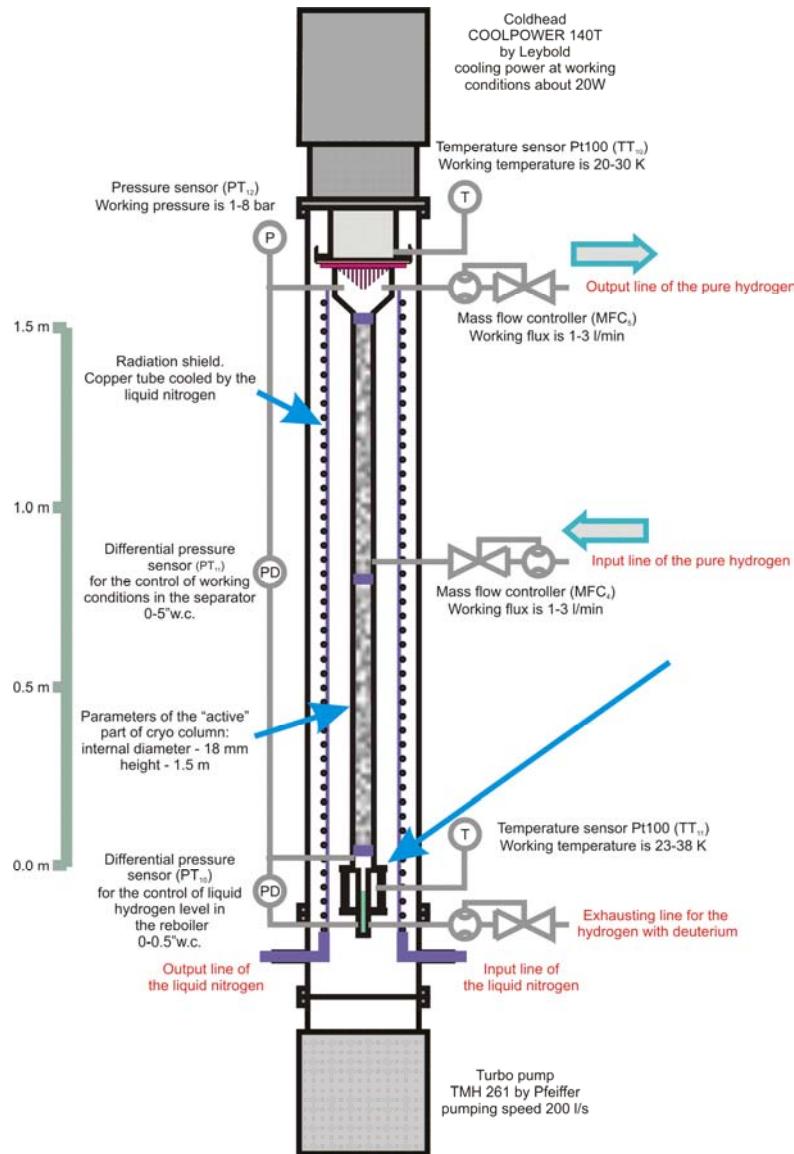
Isotopic purification

The natural water contains about 140 ppm D₂O in form HDO.

The best results of water purification is 1 ppm HDO molecules.

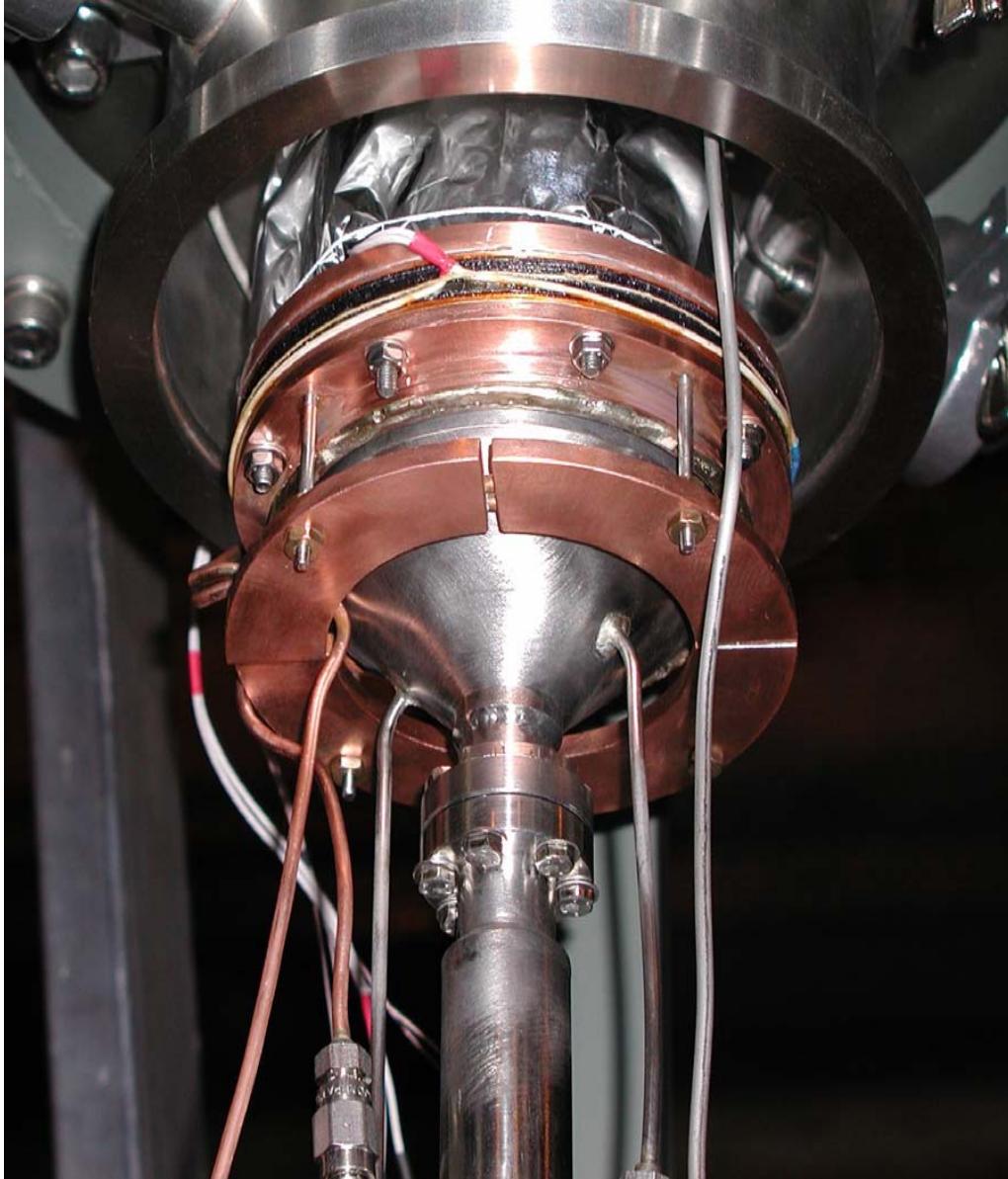
Hydrogen obtained in this work contains less than 0.006 ppm HDO.

Hydrogen isotopic purity improvement is 2 orders of magnitude!

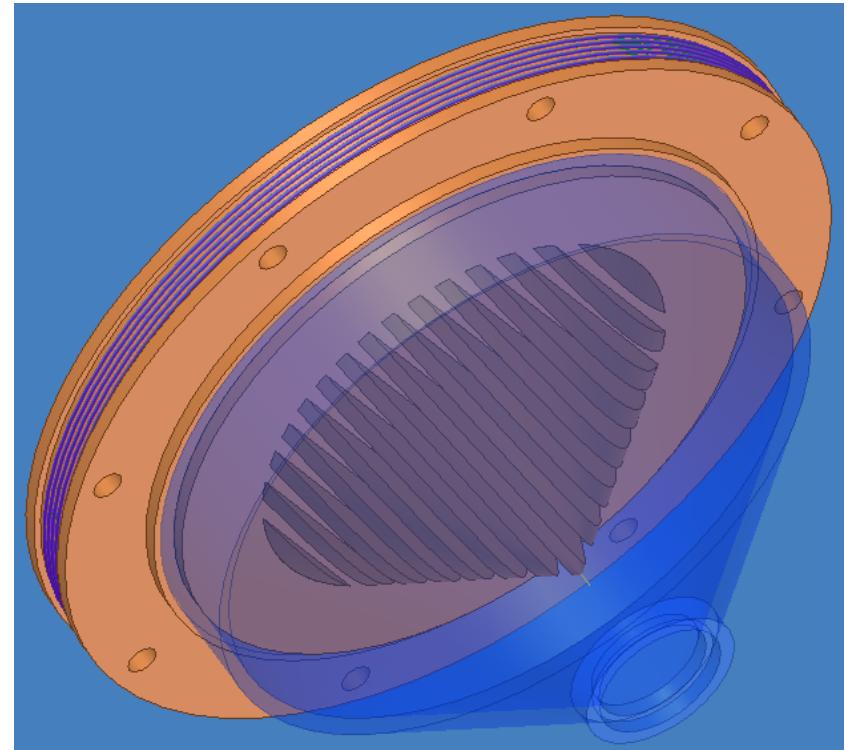




Condenser

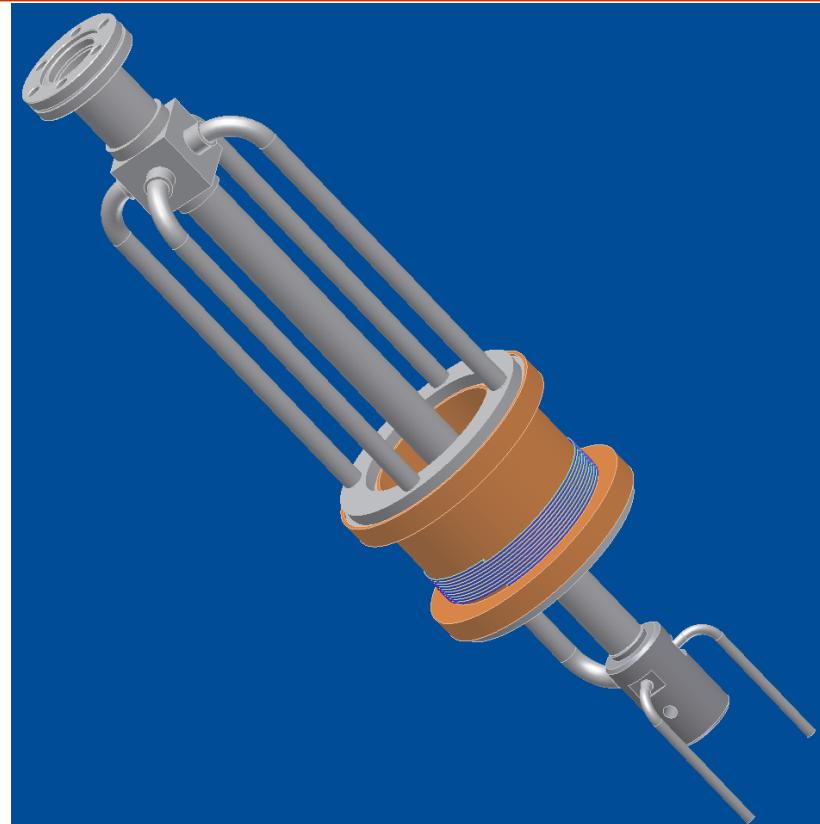


Cold head cools the big surface (200 cm^2) of the condenser and liquefies hydrogen. The drops of hydrogen fall down to the separator. The heater (HTR_1) on the side surface stabilize the temperature (or pressure) in the condenser.





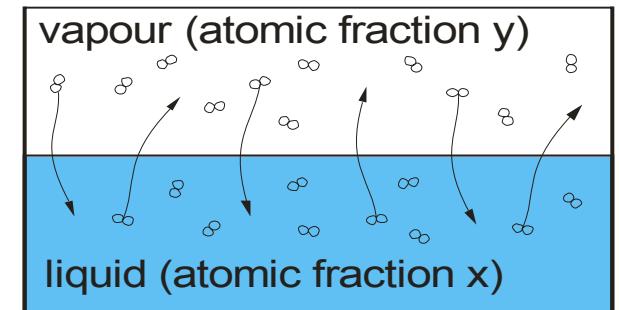
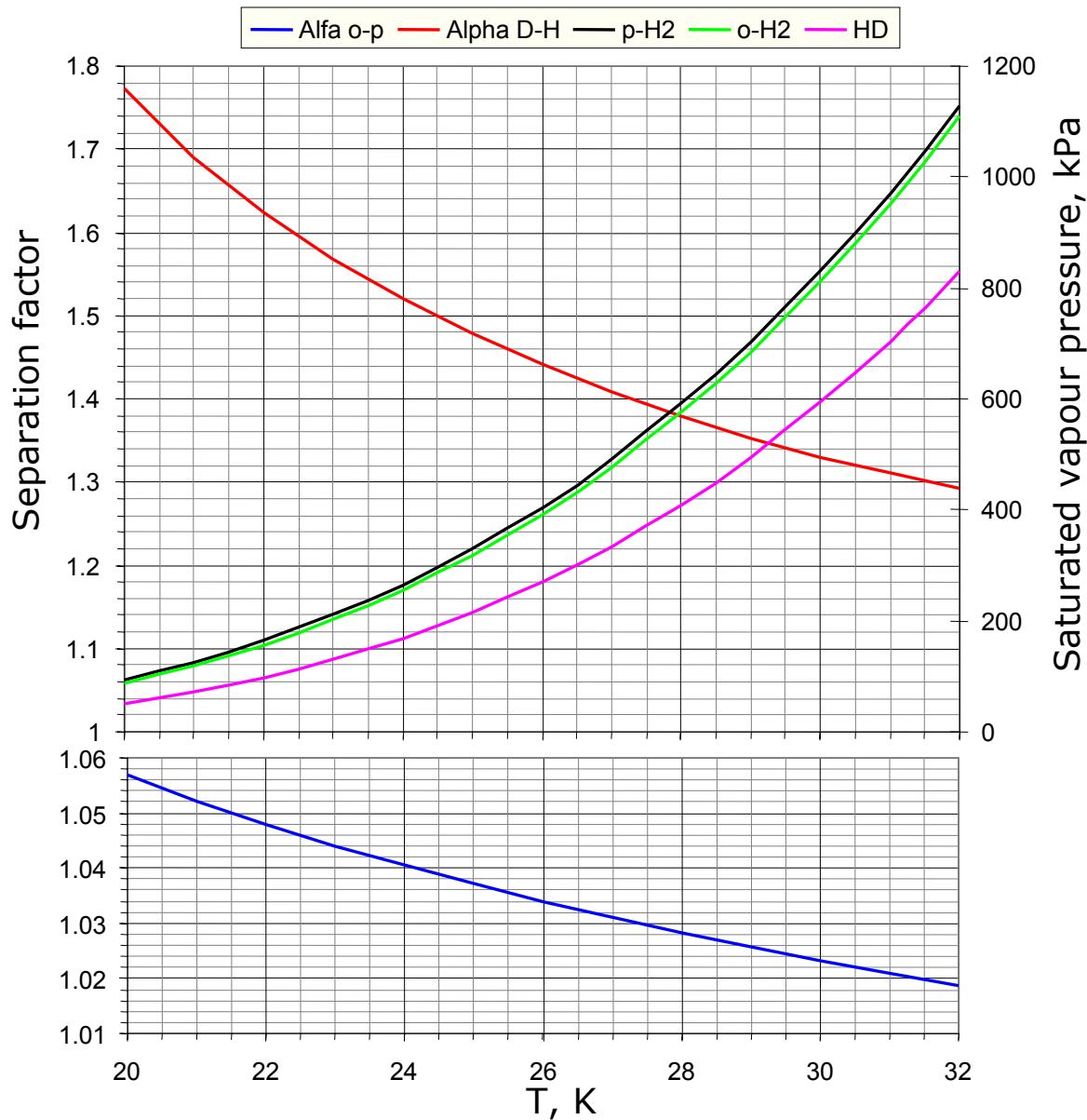
Reboiler



Liquid hydrogen enriched by deuterium is collected in the reboiler. Central tube is the storage volume for the liquid hydrogen. The side copper spool is equipped by heater. Heater (HTR_2) supports boiling conditions and convert downstream of liquid into the upstream gas flux. Four side tubes transport the gas flux upward.



Saturated vapour pressures and separation factors



Temperature = const
At dynamic equilibrium
the content of low-boiling
component is α -times higher
in liquid.
Separation factors:

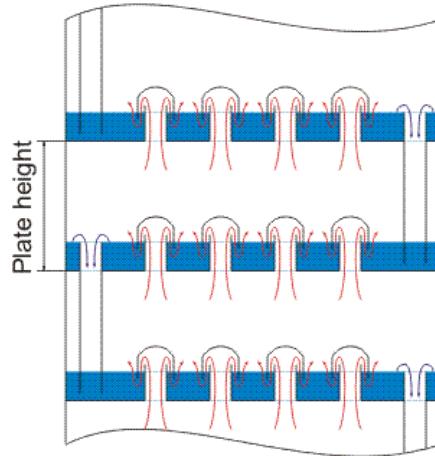
$$\alpha_{o-p} = \frac{P_{Sat.\text{Para}}}{P_{Sat.\text{Ortho}}}$$

$$\alpha_{D-H} = \frac{P_{Sat.H_2}}{P_{Sat.HD}}$$



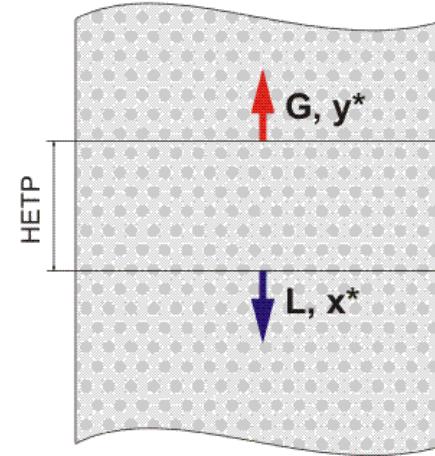
Separation column concept

Bubble cap plate



Typical plate height ~15 cm
Efficiency = 70%

Non-regular packing



Height Equivalent to a Theoretical Plate
(HETP)

Atomic fractions:

x - in liquid
y - in vapour

Separation factor:

$$\alpha = \frac{x^*/(1-x^*)}{y^*/(1-y^*)}$$

* indicates equilibrium composition

Height Equivalent to a Theoretical Plate (HEPT) is one of the main parameters of any isotope separator. This is the height of the separator element in which concentration of deuterium (in our case) drops in α times.



Packing

Characteristics:

- Type: spiral prismatic
- Size: 2x2x0.2 mm
- Free volume fraction: 0.82
- Specific surface: $3490 \text{ m}^2/\text{m}^3$
- Packed density: 1430 kg/m^3
- Material: stainless steel

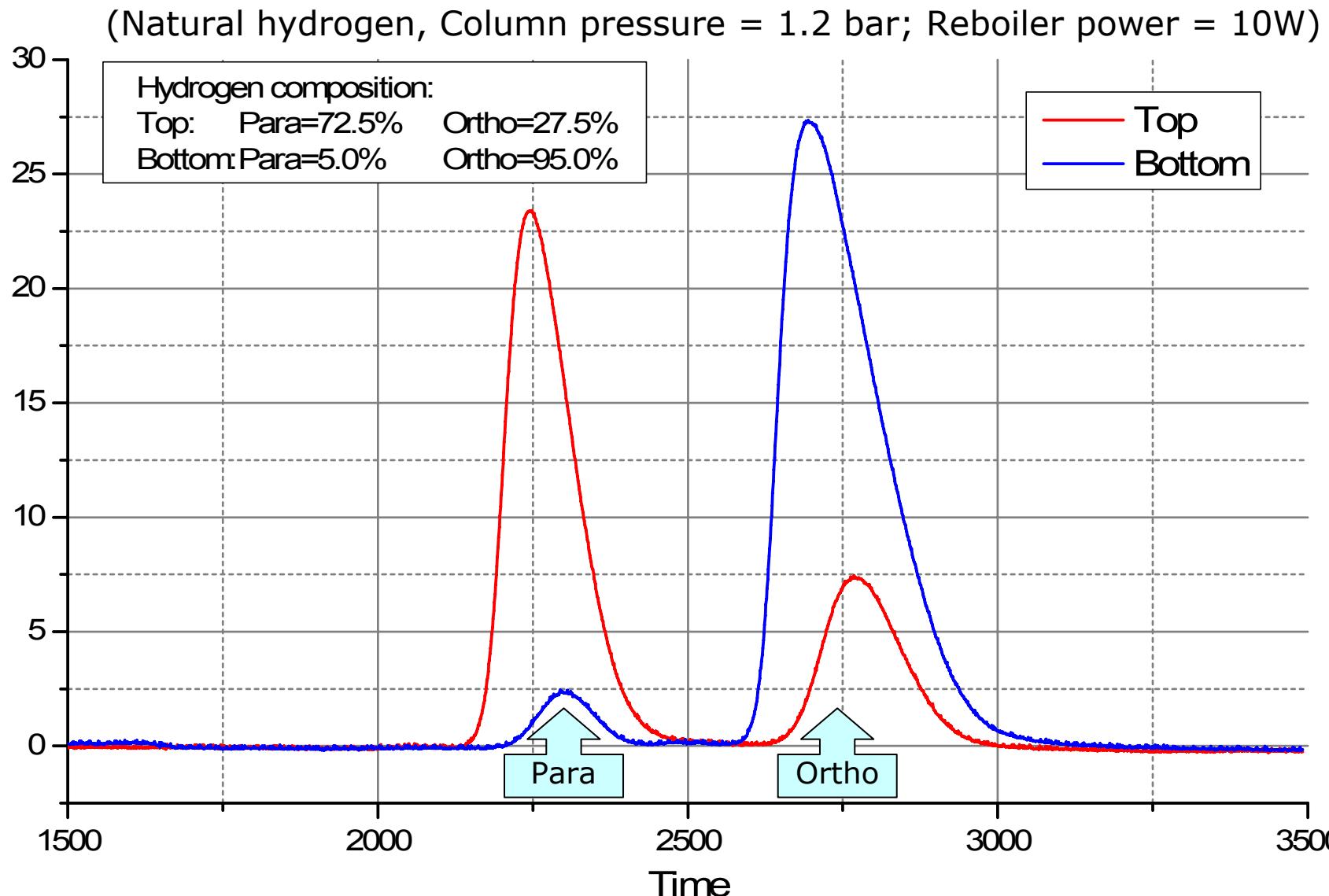


Total volume of packing
in the column = 560 ml
Total packing surface
in the column = 1.95 m^2



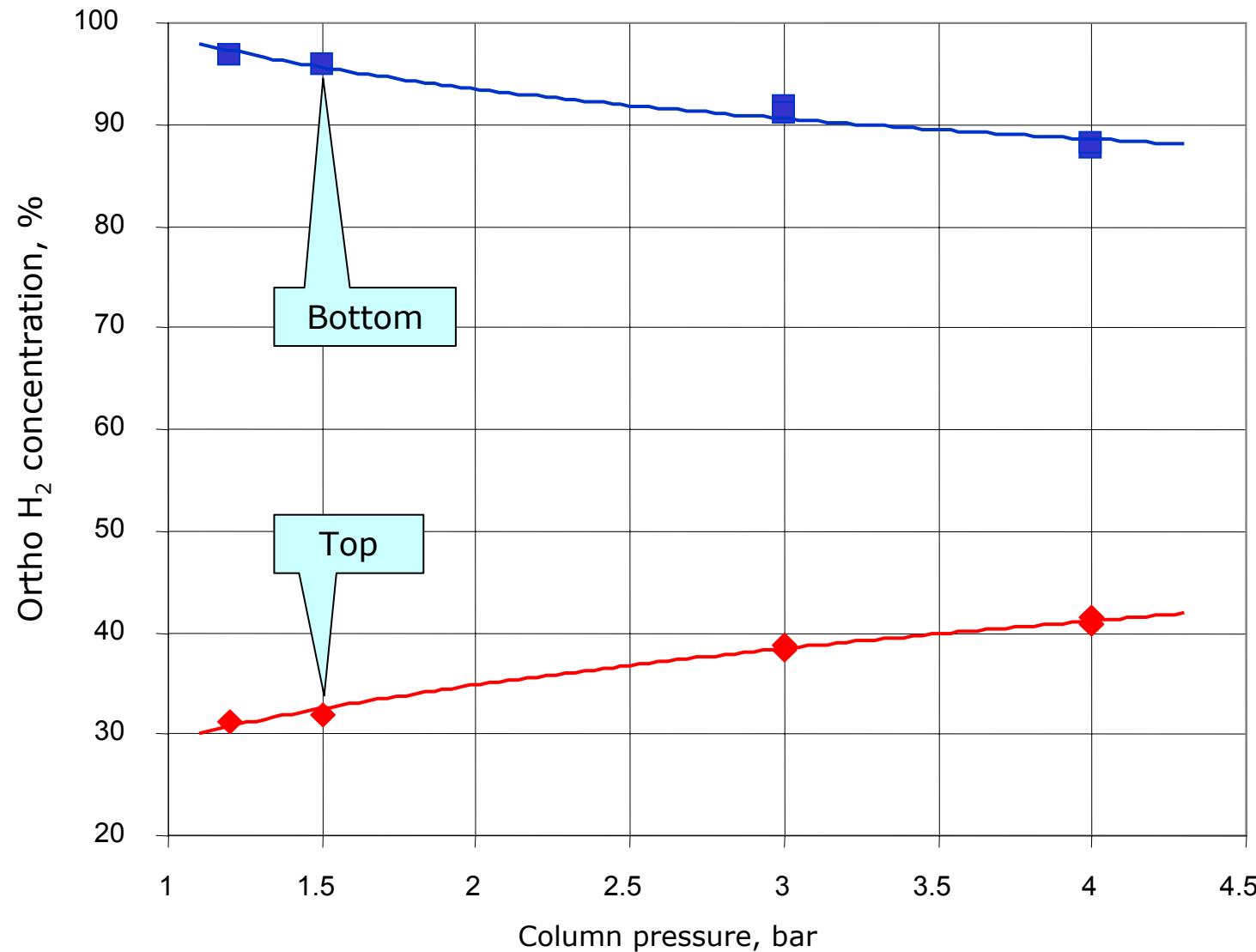


Ortho-Para Hydrogen Chromatogram



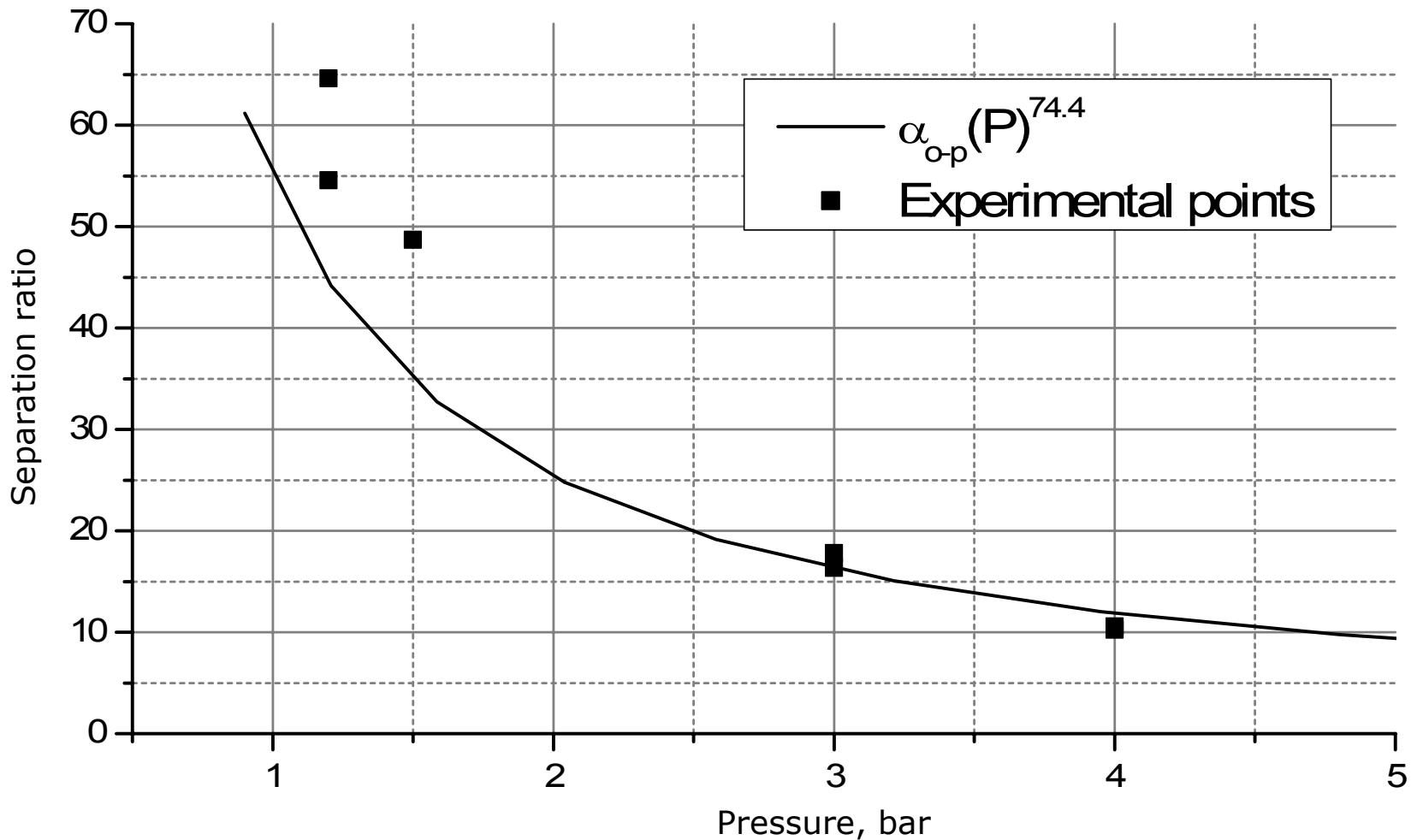


Ortho hydrogen concentration





Separation ratio (SR)

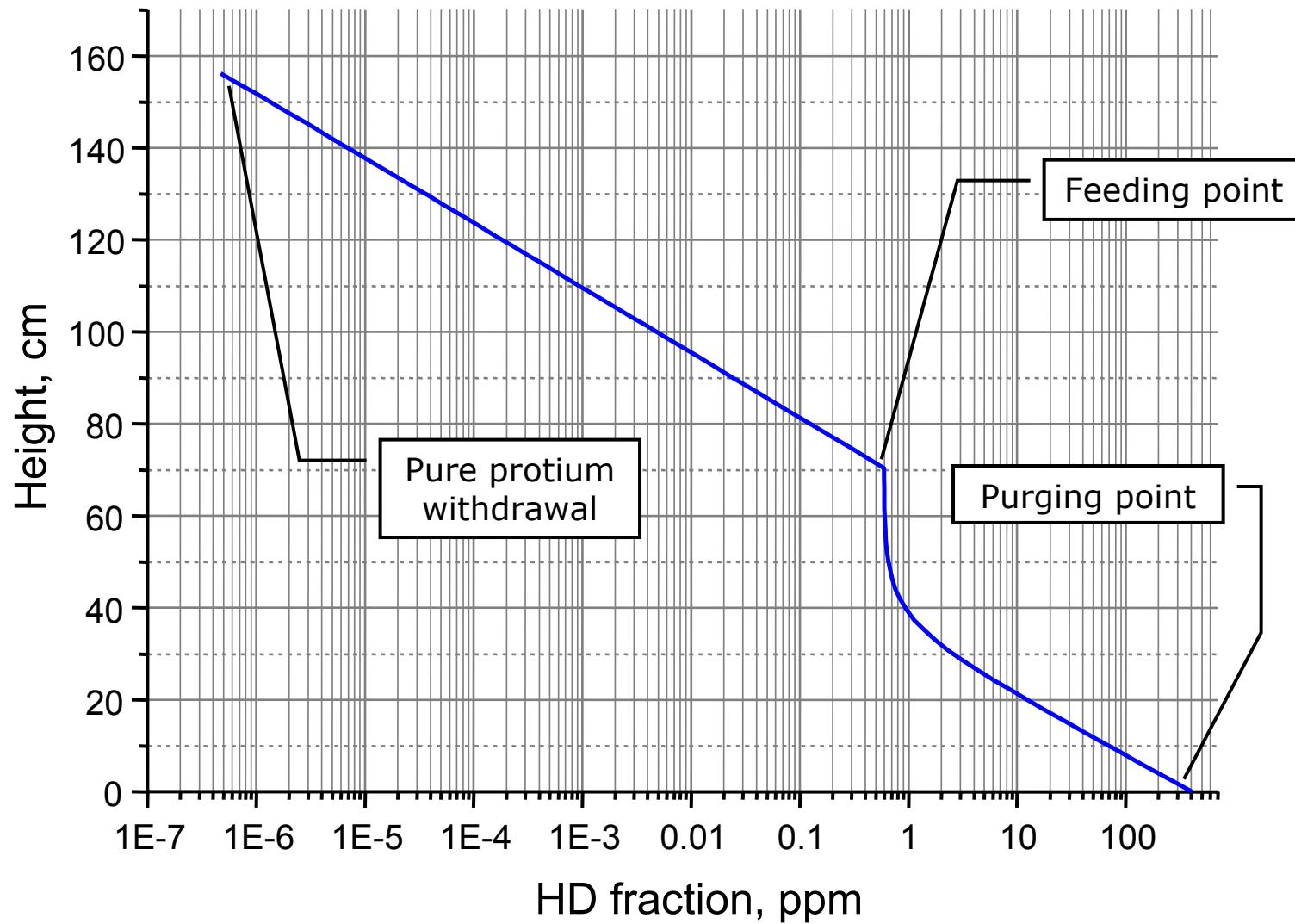


$SR = \alpha^N$ - Fenske equation for total reflux mode
(N - the number of theoretical plates)
HETP=Packing height / N

$$SR = \frac{X_{Bottom} / (1 - X_{Bottom})}{X_{Top} / (1 - X_{Top})}$$



Expected HD concentration profile

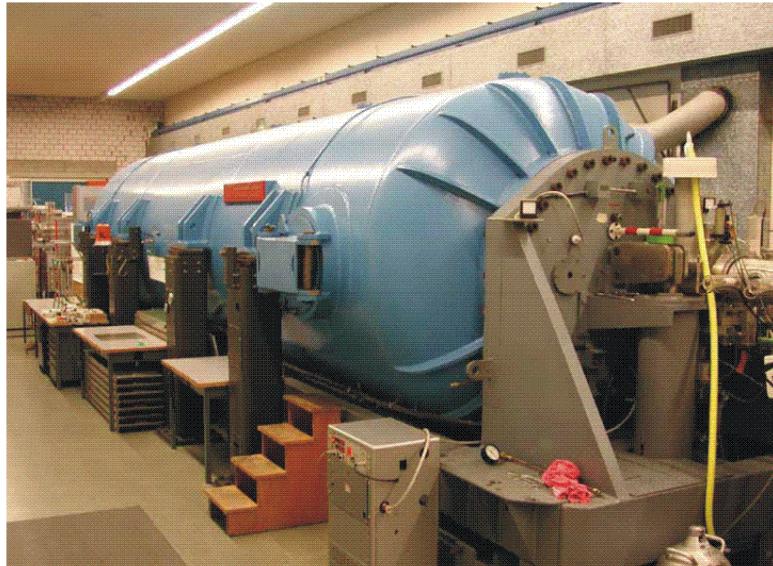


Feed flow rate = 1 L/min; Pressure = 1.5 bar; Purging flow rate = 0.015 L/min; HETP = 2.2 cm
Initial HD concentration = 6 ppm (deuterium atomic fraction = 3 ppm)



Deuterium concentration ?

Direct analyses of the deuterium concentration in hydrogen.



Institute of Particle Physics HPK, ETH Hönggerberg
CH-8093 Zurich, Switzerland

Direct measurements of deuterium concentration has been done on tandem accelerator.
This unique method and “zero” probes of the pure deuterium from separator gave
possibility to carry out analysis with the sensitivity 0.006 ppm.

M. Suter et al., Advances in particle identification in AMS at low energies.
Nuclear Instruments and Methods in Physics Research B 259 (2007) 165–172.



Main achievements

- Hydrogen production with atomic deuterium fraction less than 0.006 ppm. This is the most pure hydrogen available worldwide.
- Excellent column characteristics (HETP~22 mm) that is one of the best ever results obtained for columns of low and medium cryogenic power.
- Ortho-para chromatographic analysis provided online information about column performance.
- Continuous production of the pure ortho- or para- hydrogen is possible in the cryogenic column.



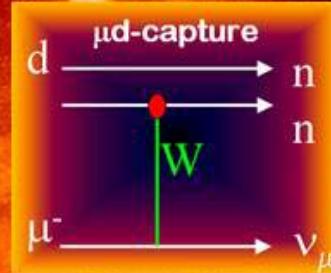
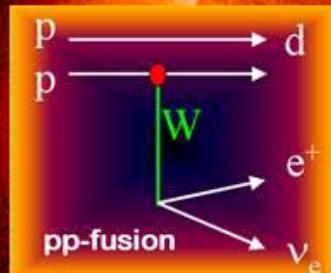
μCap collaboration, last beam time





“Calibrating the Sun” via Muon Capture on the Deuteron

“MuSun”



model-independent connection via EFT & L_{1A}

Goal

total μd capture rate to 1% precision

Motivation

- first precise measurement of basic EW reaction in 2N system,
benchmark measurement with 10x higher precision
- impact on fundamental astrophysics reactions (SNO, pp)
- comparison of modern high precision calculations
- high precision feasible by μ Cap technique and careful optimization



Working conditions:

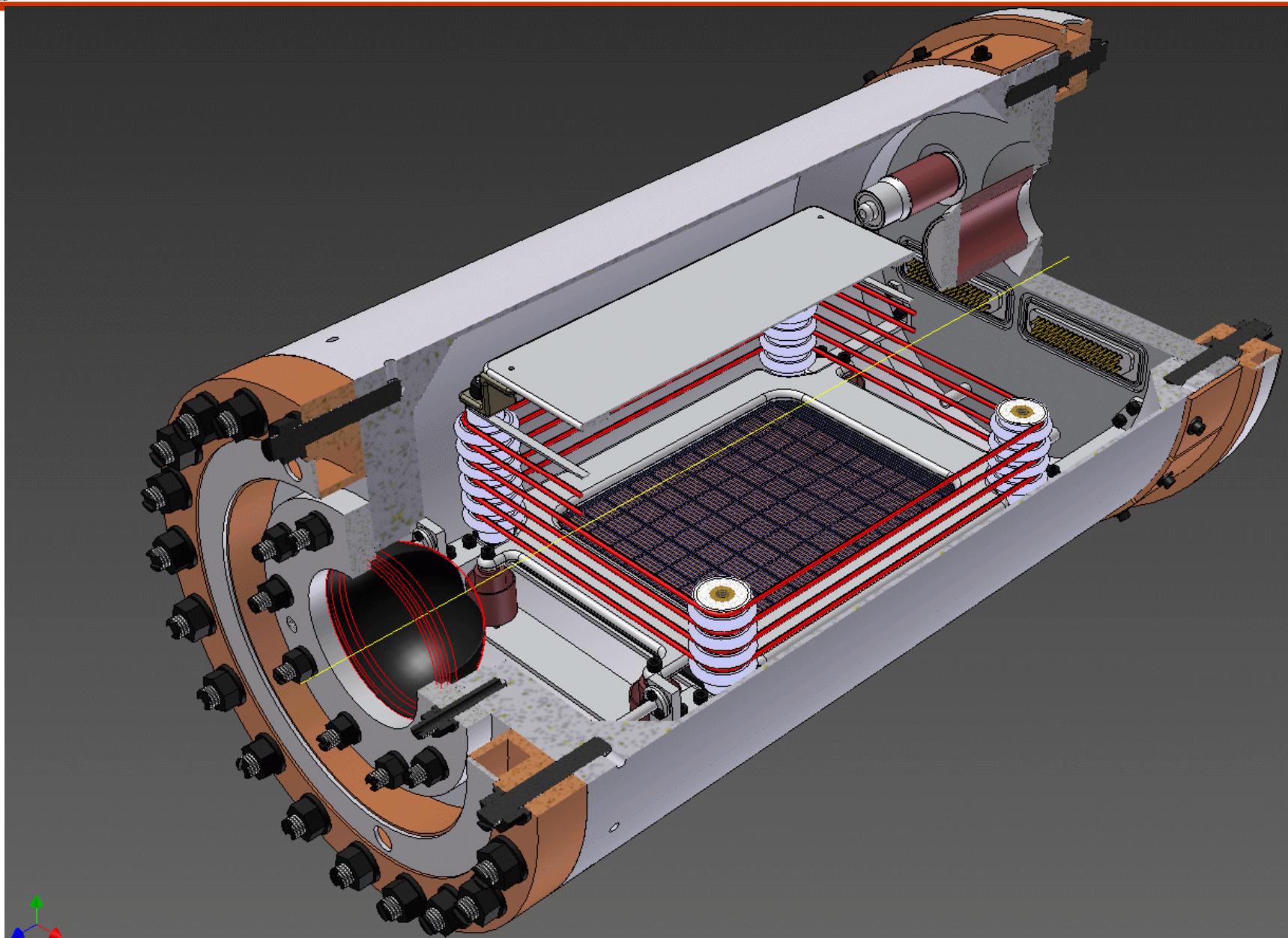
temperature of Cryo_TPC - 30-32 K;

deuterium pressure inside the chamber - 5 bar;

sensitive volume: along the beam 130 mm x 100 mm x 80 mm;

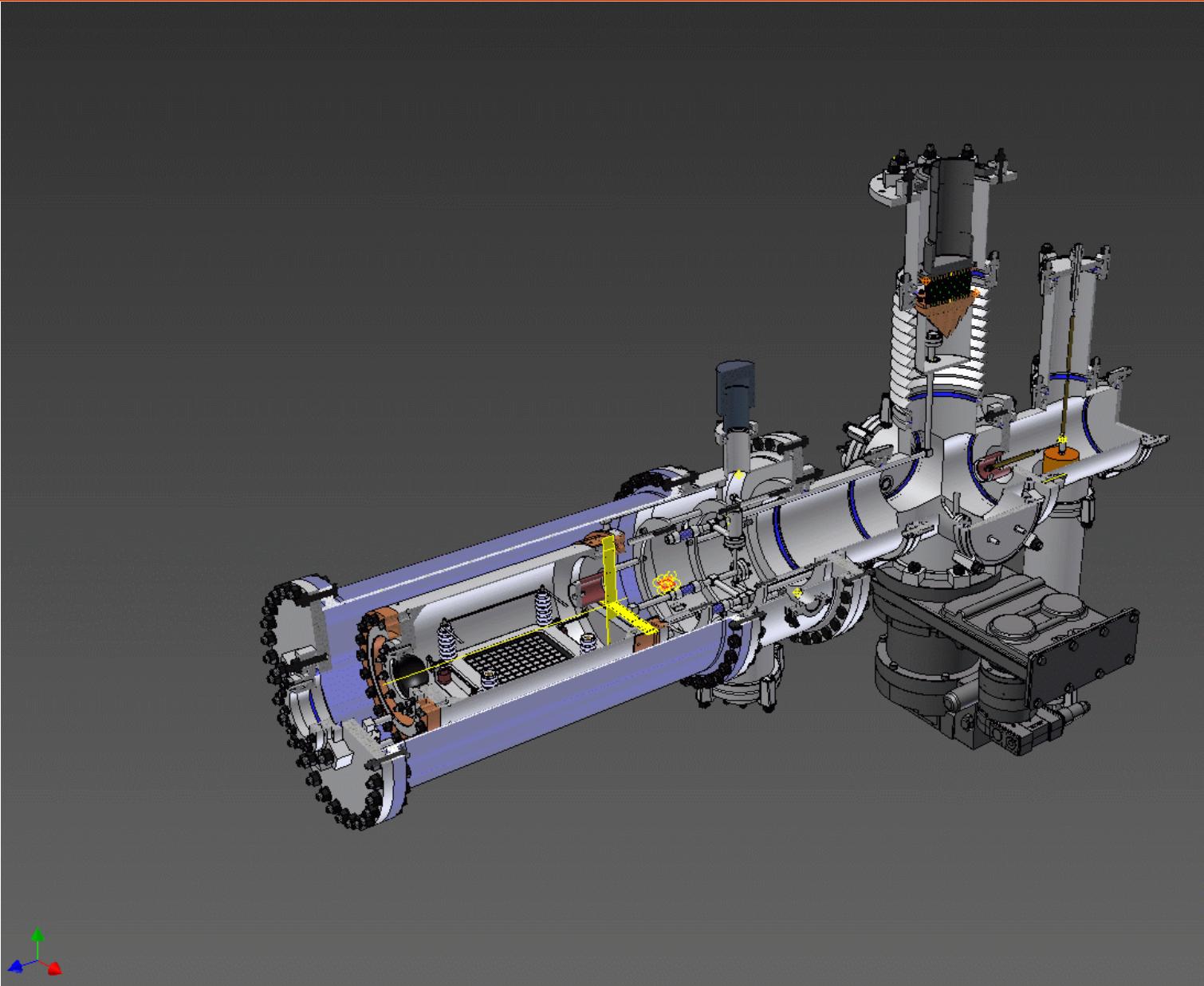
cathode potential 80-100 kV, electrical field 10-12 kV/cm;

greed-anode distance 1-1.5 mm, potential – 2-5 kV.



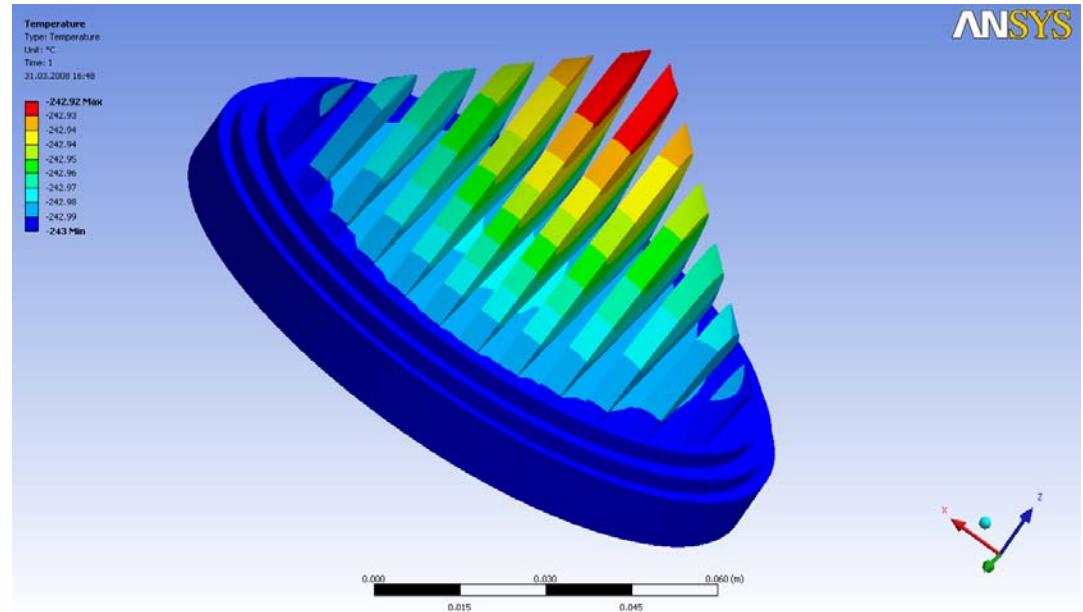
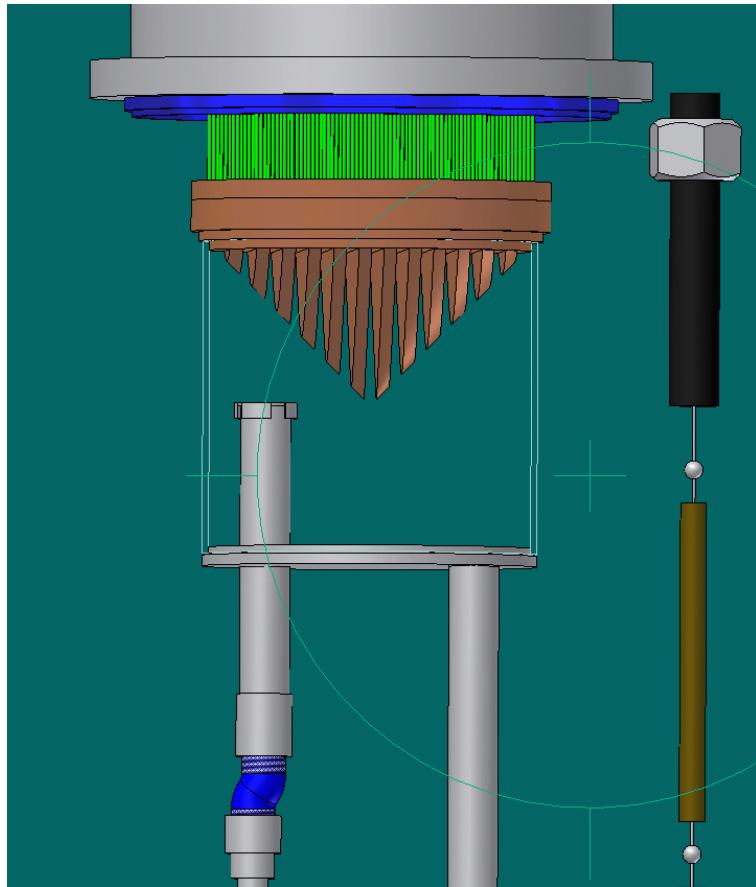


Cooling system





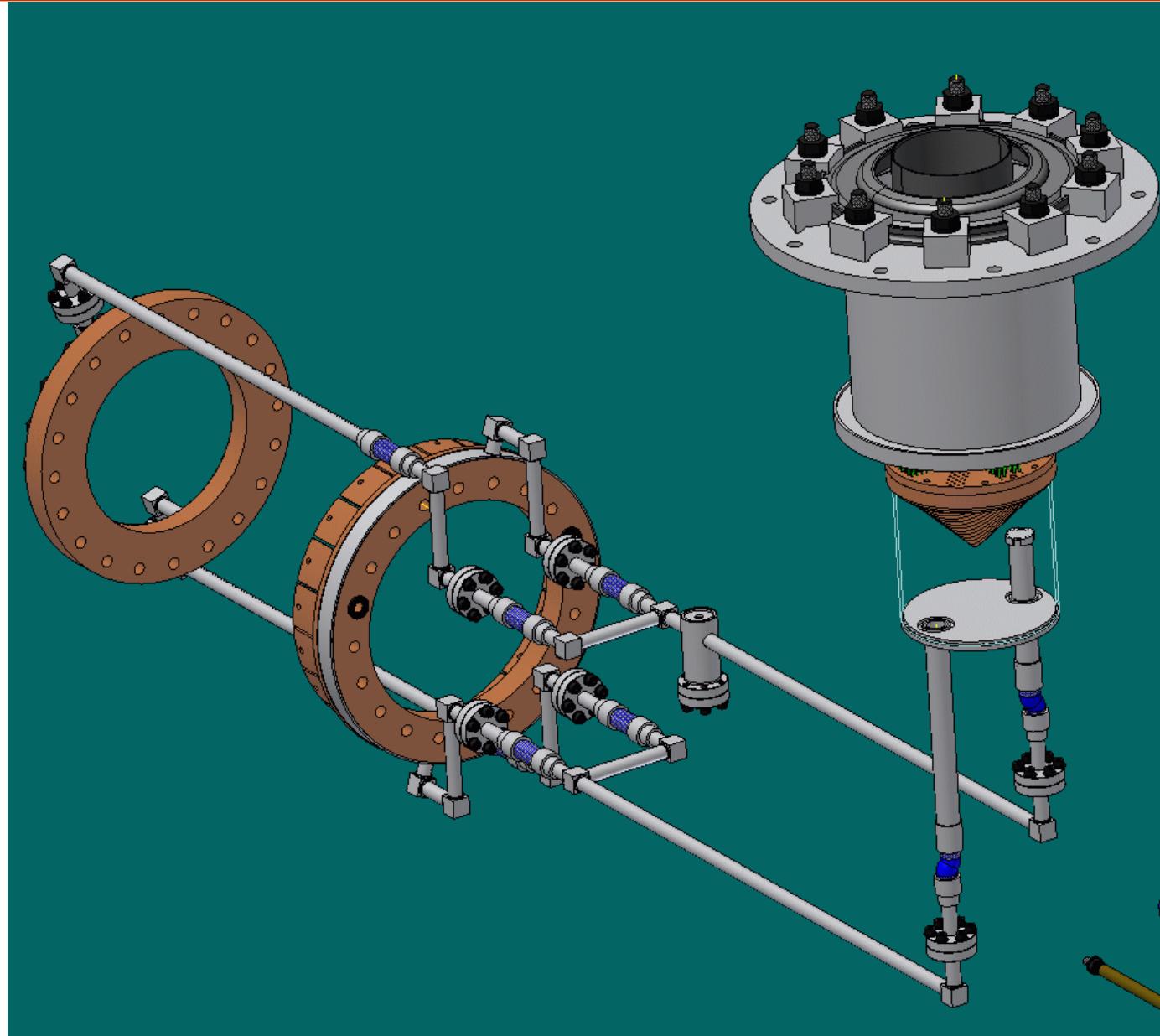
Cooling system



32 K – 26 W cooling power

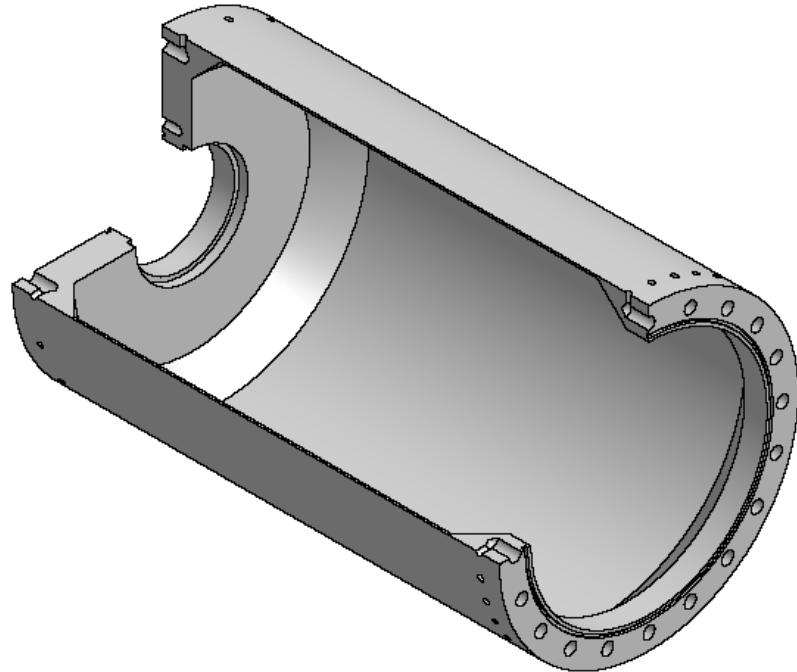


Cooling system



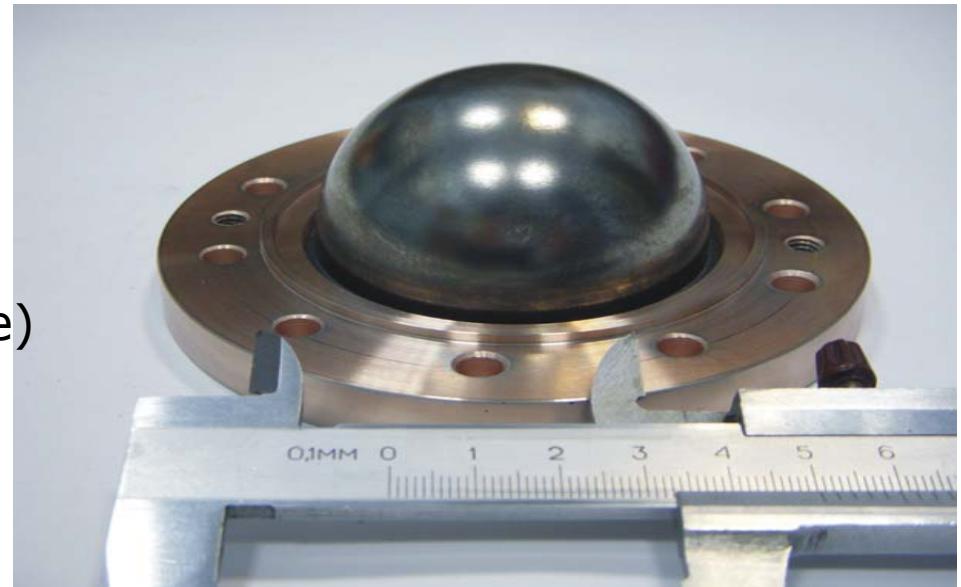


Chamber and window



Diameter 60 mm
Thickness 0.4 mm

Tested at 26 bar (room temperature)
15 bar (liquid nitrogen)
15 bar (120 C)





Invitation

Today at 15:00 you can visit us and to see working circulation system and isotopic separator.

Thanks!