# Molecular beam of polarized hydrogen

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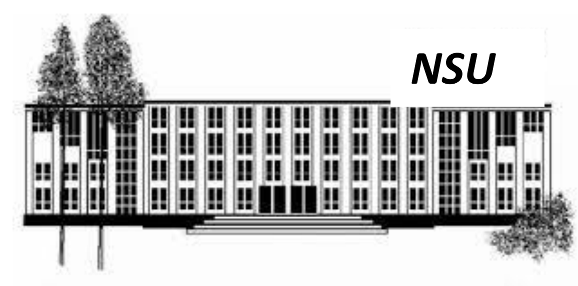
BINP



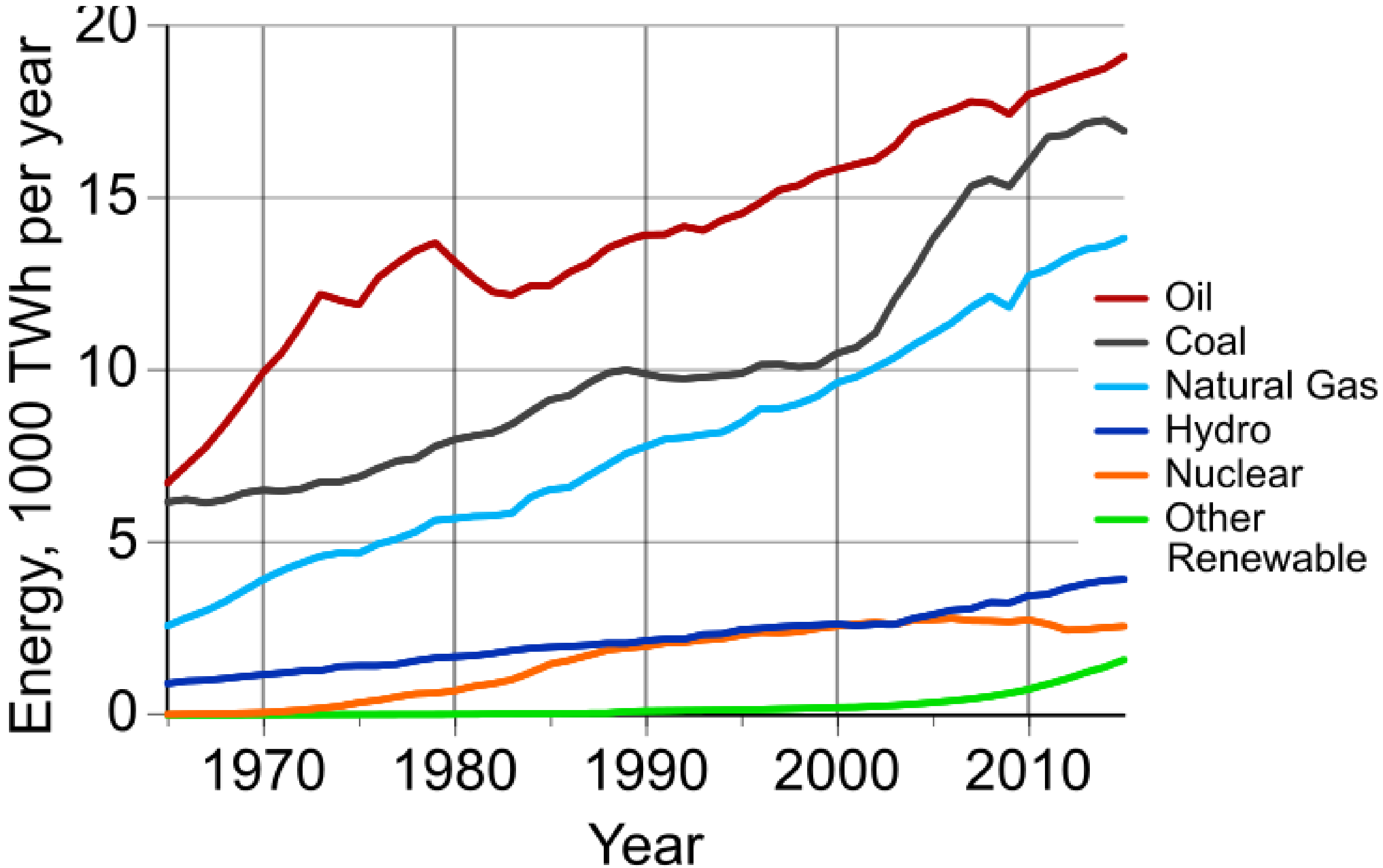
# Outline

- **Why do we need polarized particles**
- **Sources of polarized particles**
- **Possible source of polarized molecules**
- **Source of polarized molecules based on CABS**
- **Results of measurements**
- **Discussion**
- **Future prospect**
- **Conclusion**

# The future of energy

Currently, there are many scientific articles on issues of the energy provision of mankind in the future. Basically the global energy production is dominated by fossil natural sources up to now. In the future, other sources of energy are needed.

# WORLD ENERGY CONSUMPTION



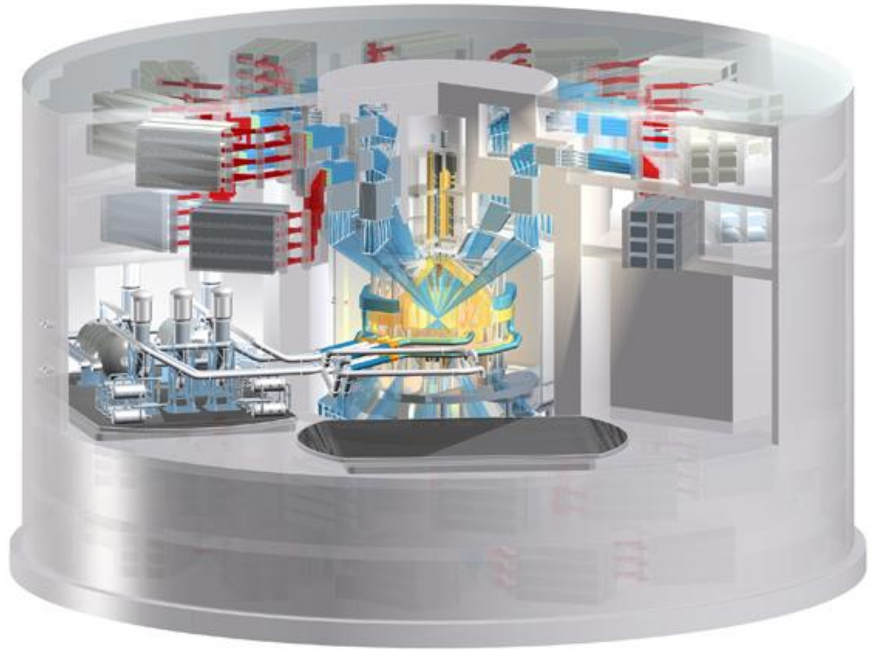

A fundamental change is coming sooner than we might think

# Fusion is the most valuable source of energy for the future

## *Two directions to produce fusion energy are in progress*

**ITER, JULY 2016**

**International Thermonuclear Experimental Reactor the world's largest magnetic confinement plasma physics experiment**



**Laser Inertial Fusion Energy (LIFE)**

# The most important thermonuclear reactions

**1st generation D + T $\longrightarrow$ n (14.1 MeV) + $^4$He (3.5 MeV),**

**2nd generation D + D $\longrightarrow$ n (2.45 MeV) +**
**$^3$He (0.82 MeV) (50 %),**
**p (3.02 MeV) + T (1.01 MeV) (50 %),**

**3rd generation D + $^3$He $\longrightarrow$ p (14.7 MeV) +**
**$^4$He (3.6 MeV) neutron free reaction.**

# Why do we need polarized particles

The amplitudes of the important fusion reactions: 1st and 3rd generation are dominated by the S wave $J^P = 3/2^+$ resonance.

A simple counting of spin states implies that in an unpolarized plasma only 2/3 of nuclei can undergo the fusion.

Alternatively, a full polarization of the deuteron and $^3$He would enhance the fusion cross section by 50%. Such a strong polarization effect has been confirmed experimentally to a good accuracy.

The relatively good knowledge about these two reactions allows the conclusion that with polarized beams and targets an enhancement of the fusion yield close to a factor of 1.5 may be expected.

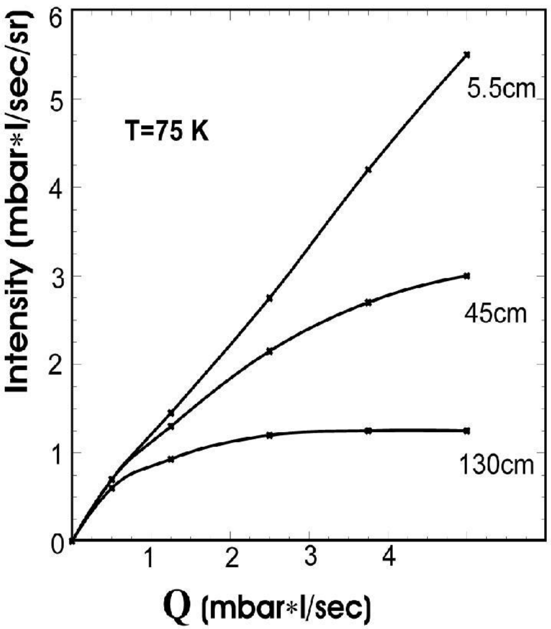
R. M. Kulsrud et al., Phys. Rev. Lett. 49, 1248 (1982).

H. Paetz gen. Schieck, Eur. Phys. J. A 44, 321 (2010).

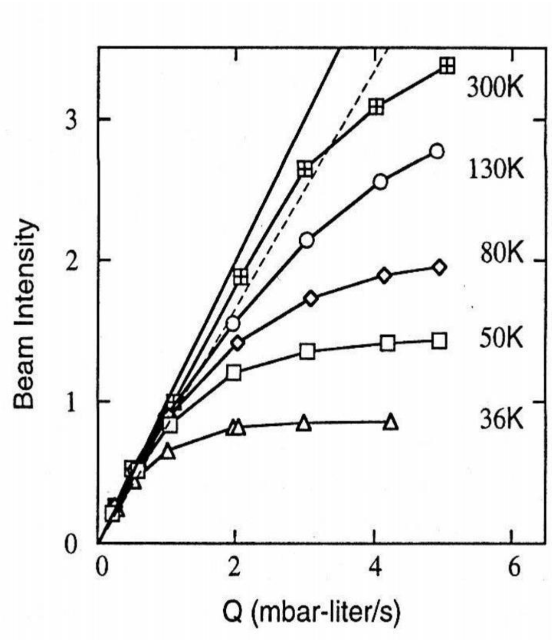
# Sources of polarized atoms

The sources of polarized atoms (ABS) has been developed from the early 50$^{th}$. Since there fast developing this technique now reached limit in the intensity of polarized atoms.  The best sources deliver about $10^{17}$ atoms/s

# At large distances or low temperature of the beam intrabeam scattering limits the intensity.




FILTEX ABS, 1991




T.Wise et al. NIMA 336(1993) 410

***Intensities of the free hydrogen molecular beams***.

# How to increase the intensity of polarized beams?

**To overcome intrabeam scattering:**

**Low density in the beam,**

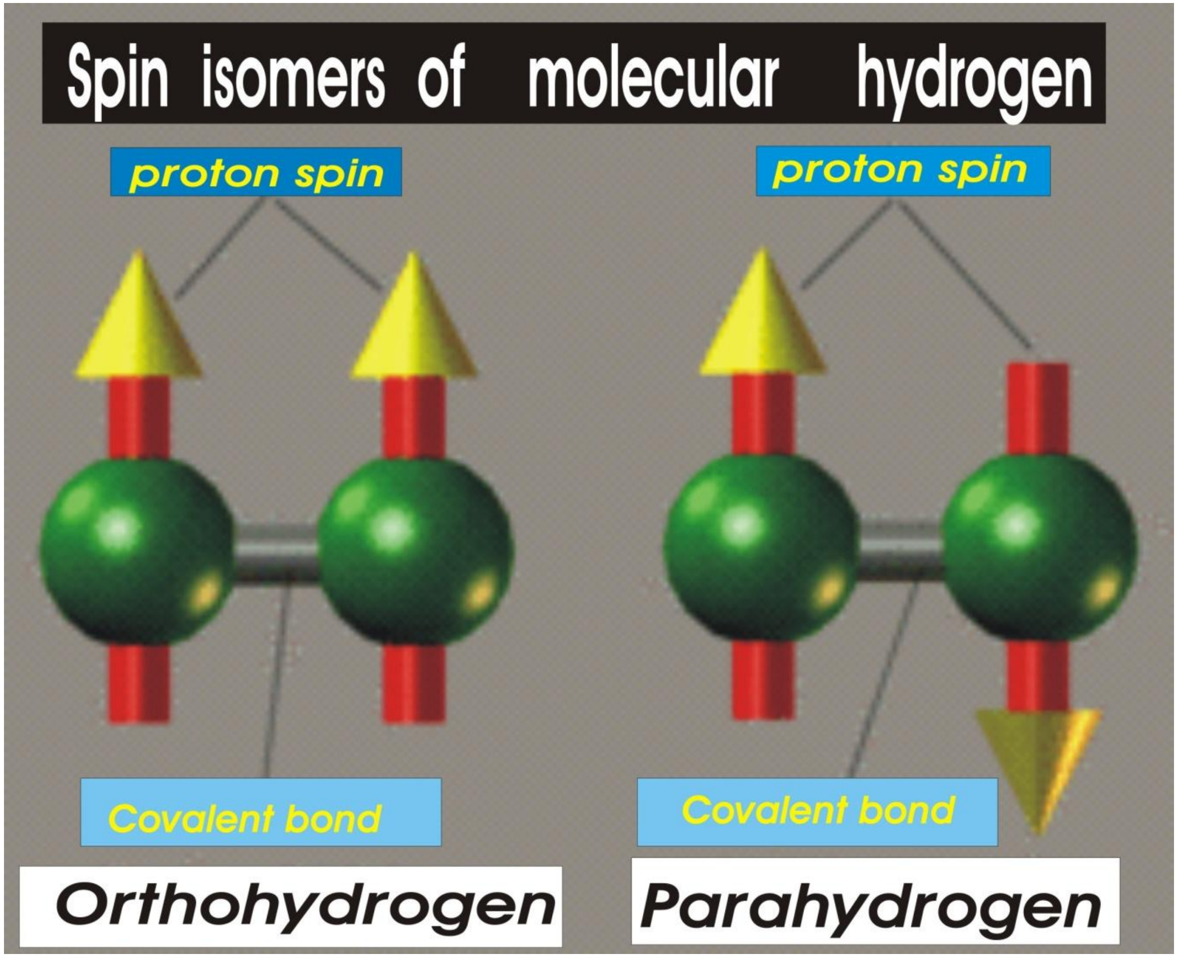
**Free molecular flow,**

**Large aperture of the source.**

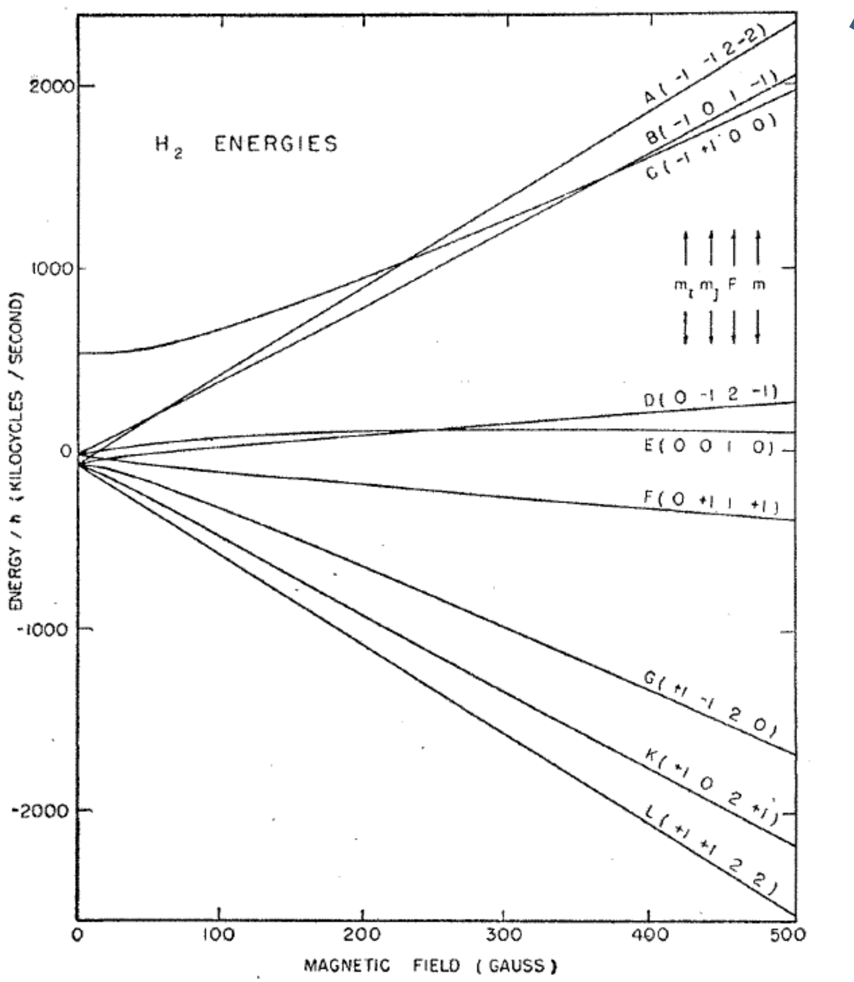
**All these features are not suitable for ABS.**

**It could be possible for molecular beam with large aperture?**

# Ortho and parahydrogen



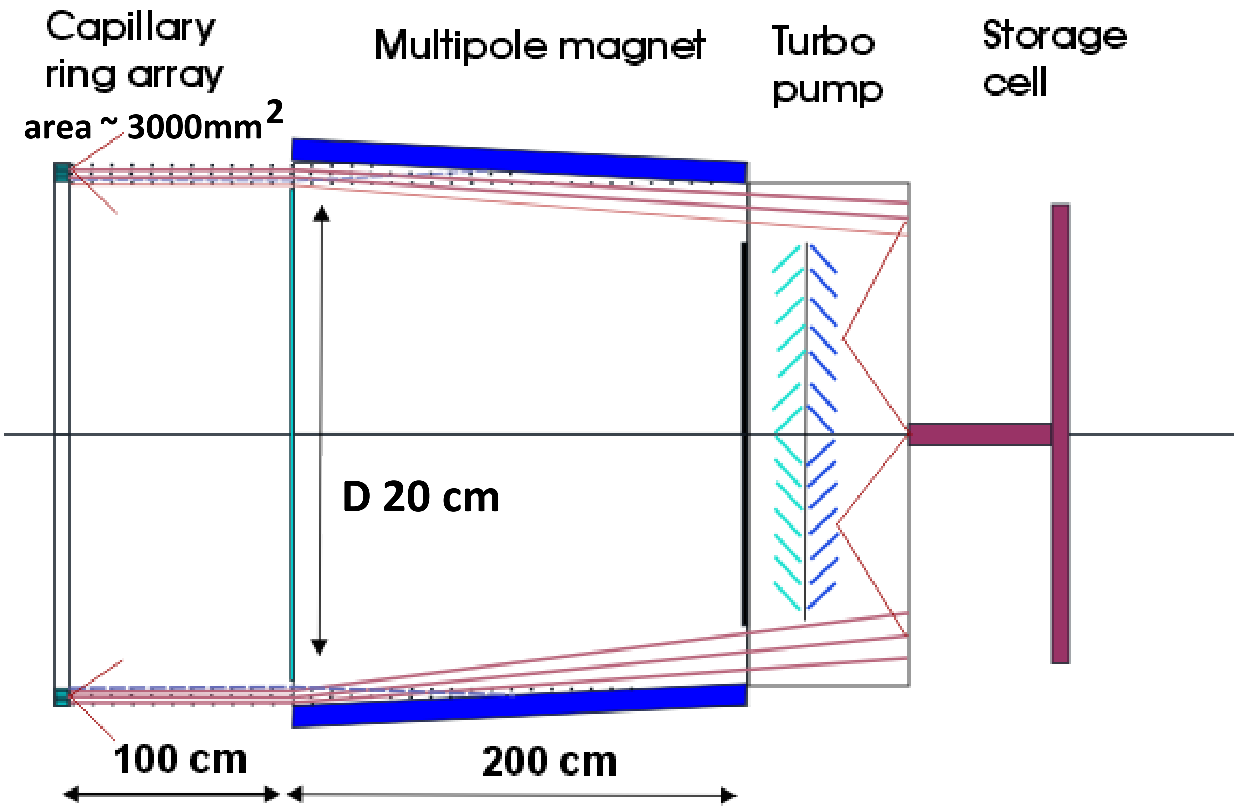
# The hyperfine energy levels of hydrogen molecule as a function of the magnetic holding field (Breit-Rabi diagram).



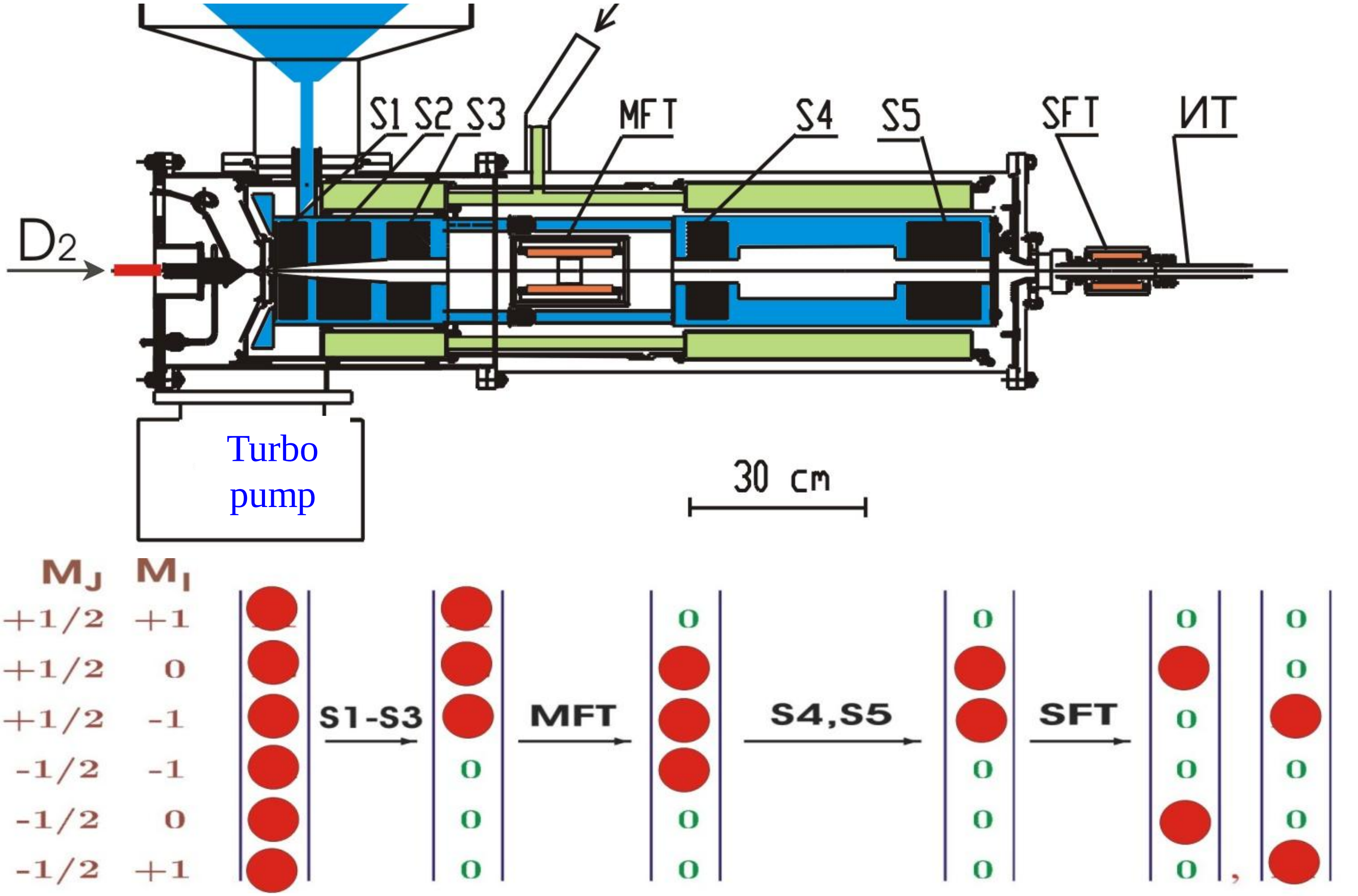

**These substates can be focused in inhomogeneous magnetic field**

Molecular Beams
Norman F. Ramsey

# Possible setup of future polarized hydrogen molecules source



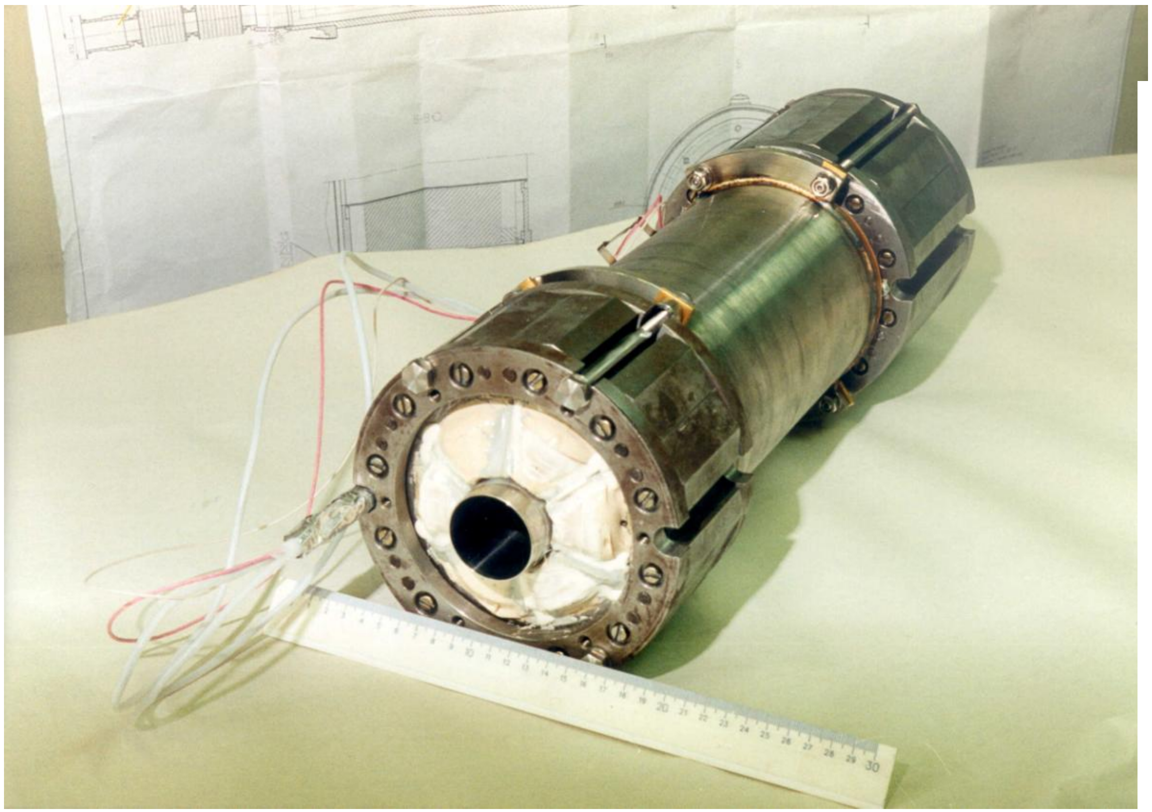
# Novosibirsk Cryogenic Atomic Beam Source

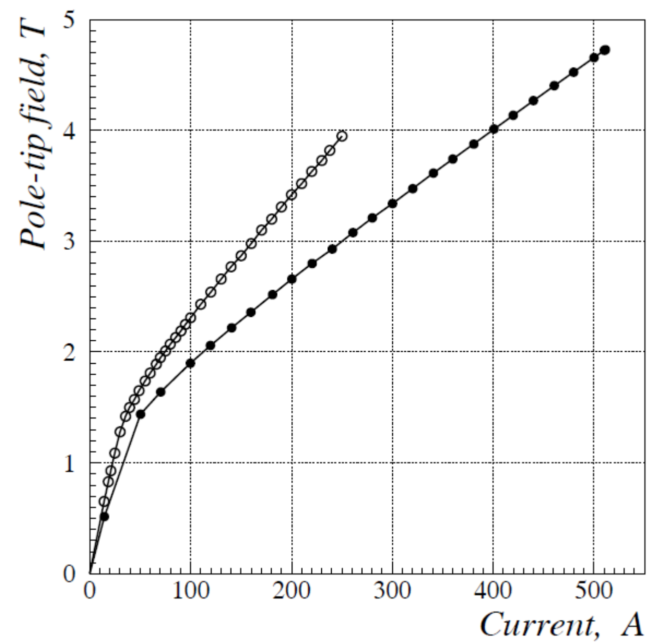



Tensor polarization $P_{zz}=1-3n_0= -2,+1.$

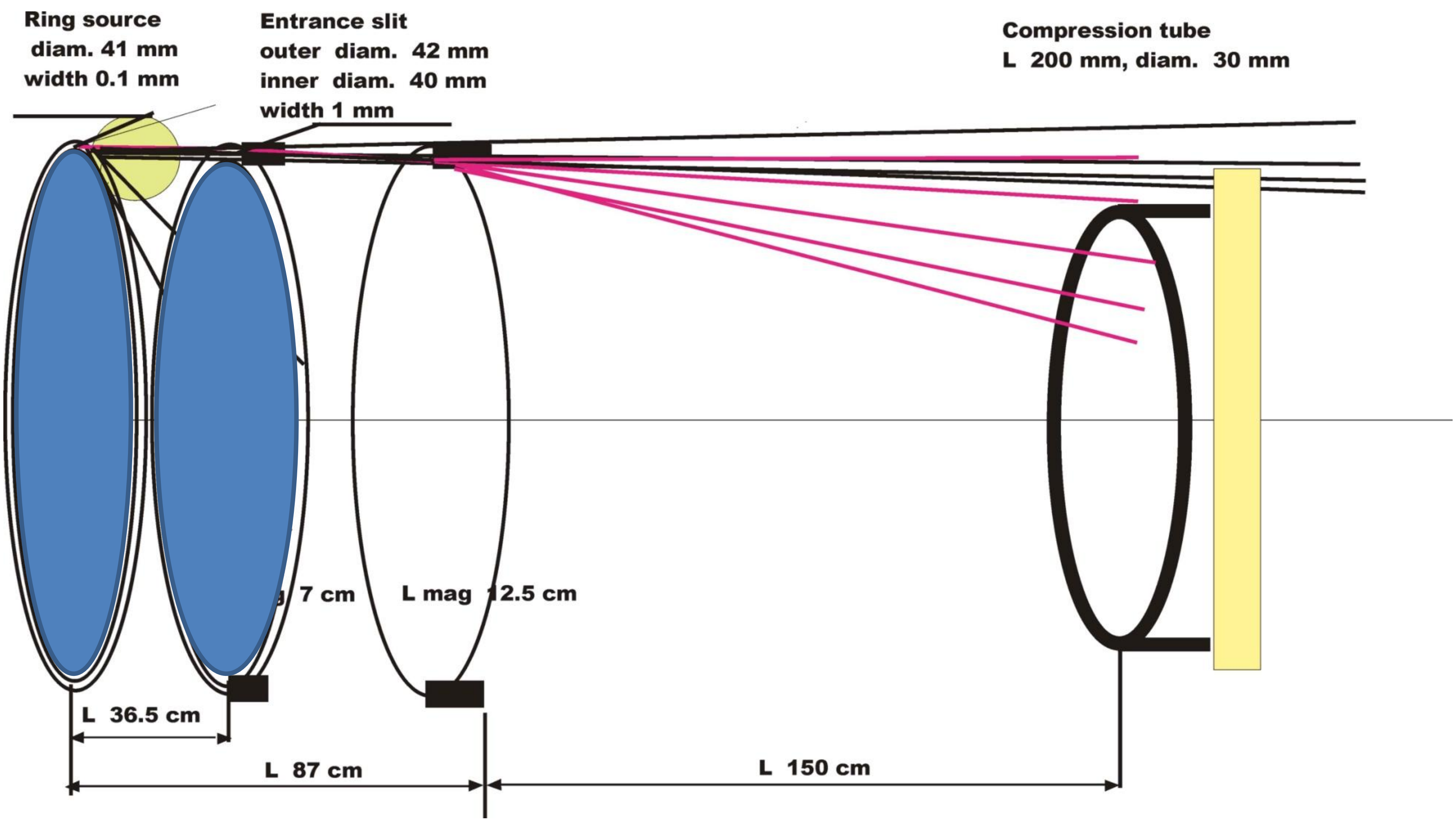
Vector polarization $P_z=n_+-n_- = 0.$

# Superconducting sextupole magnets with constant aperture 42 mm inner diam. used in ABS

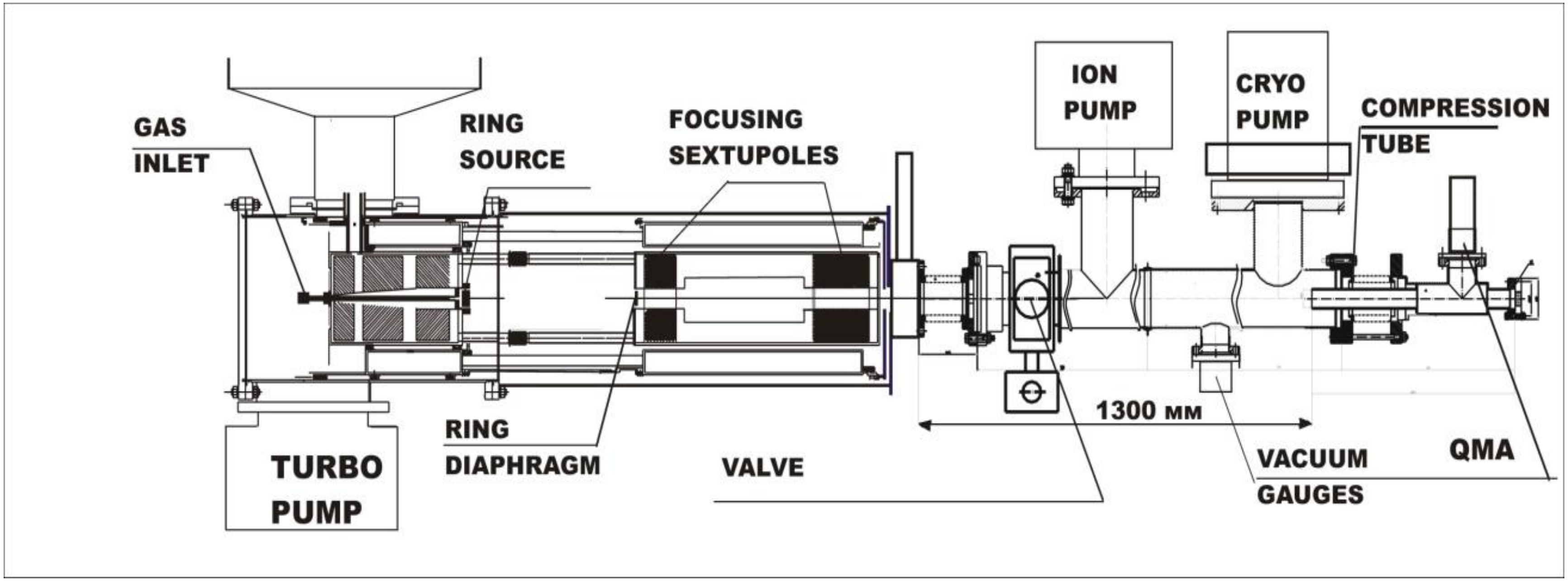




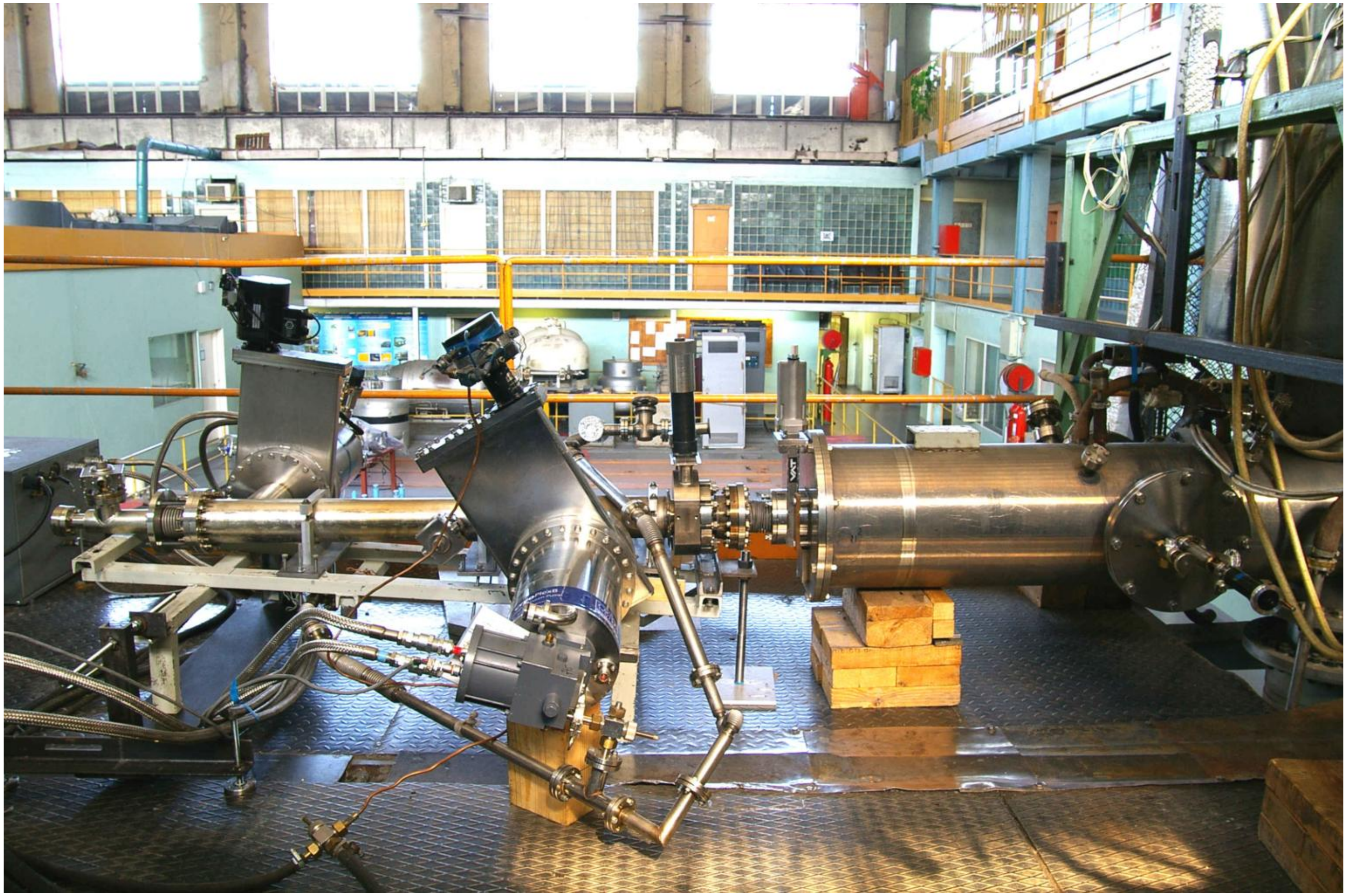
# Idea to obtain polarized molecules in existing cryogenic ABS



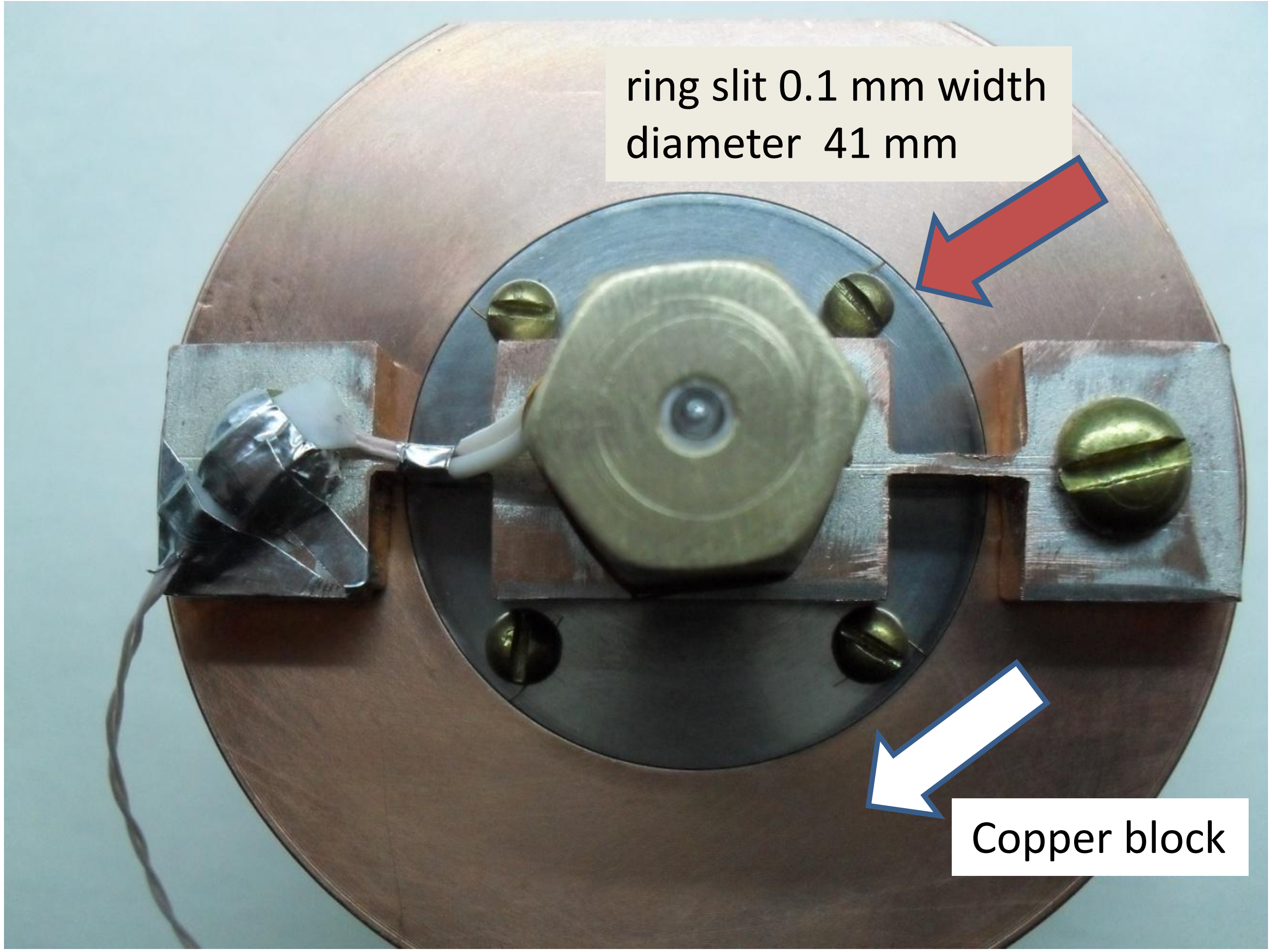
# Experimental setup to obtain polarized molecules



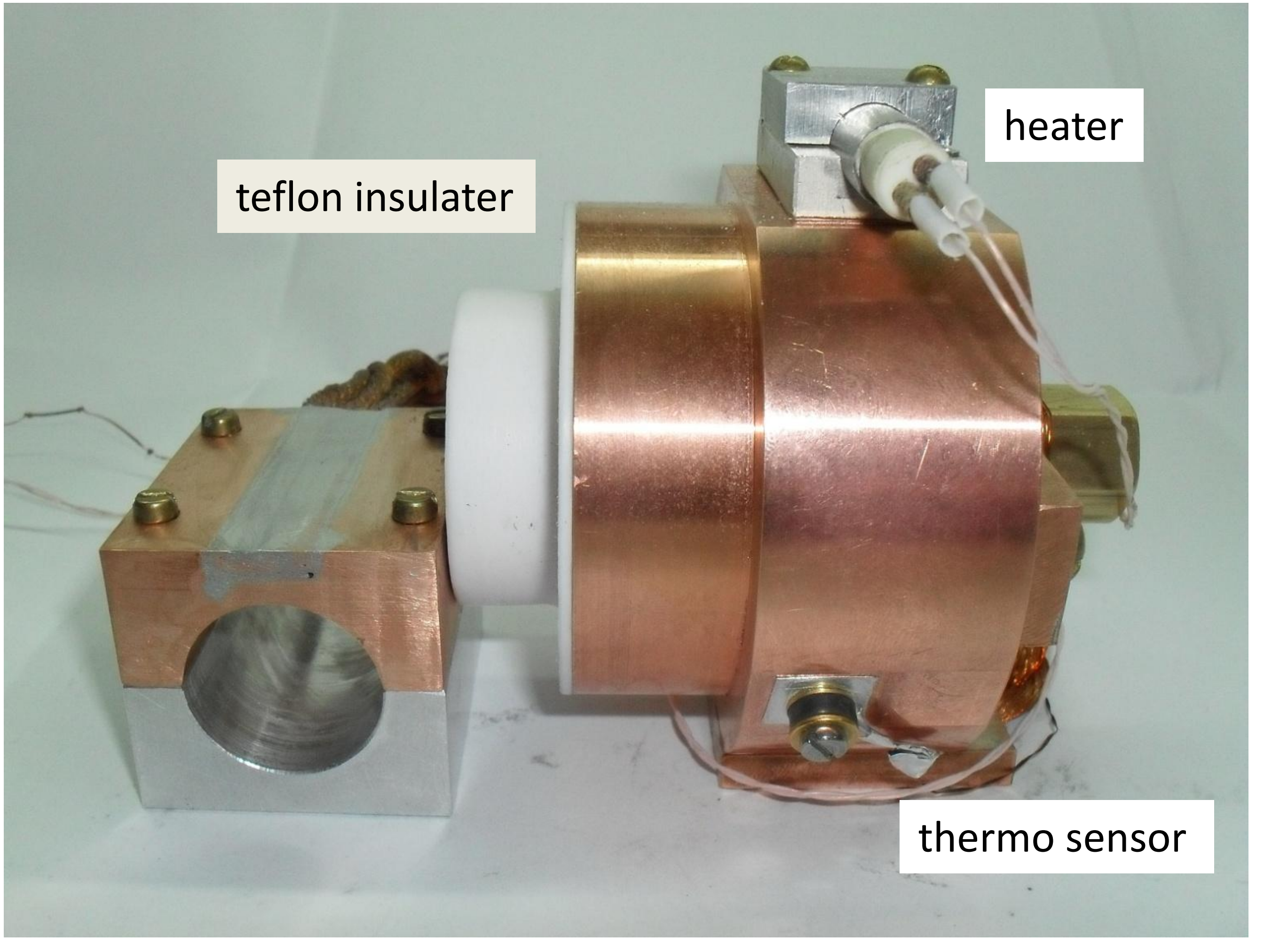
# The source of polarized hydrogen molecules at the test bench



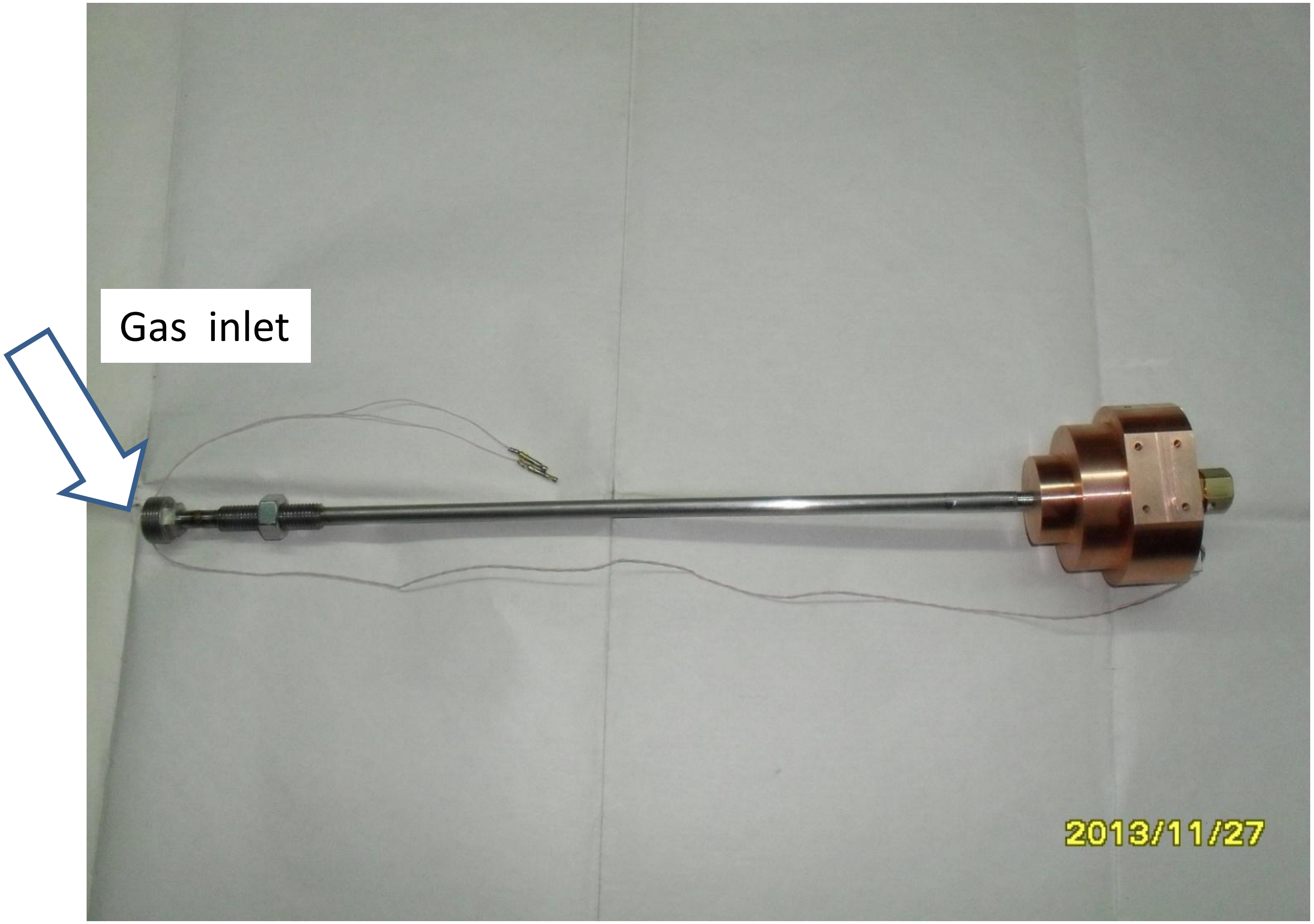
# Source of cold hydrogen molecules



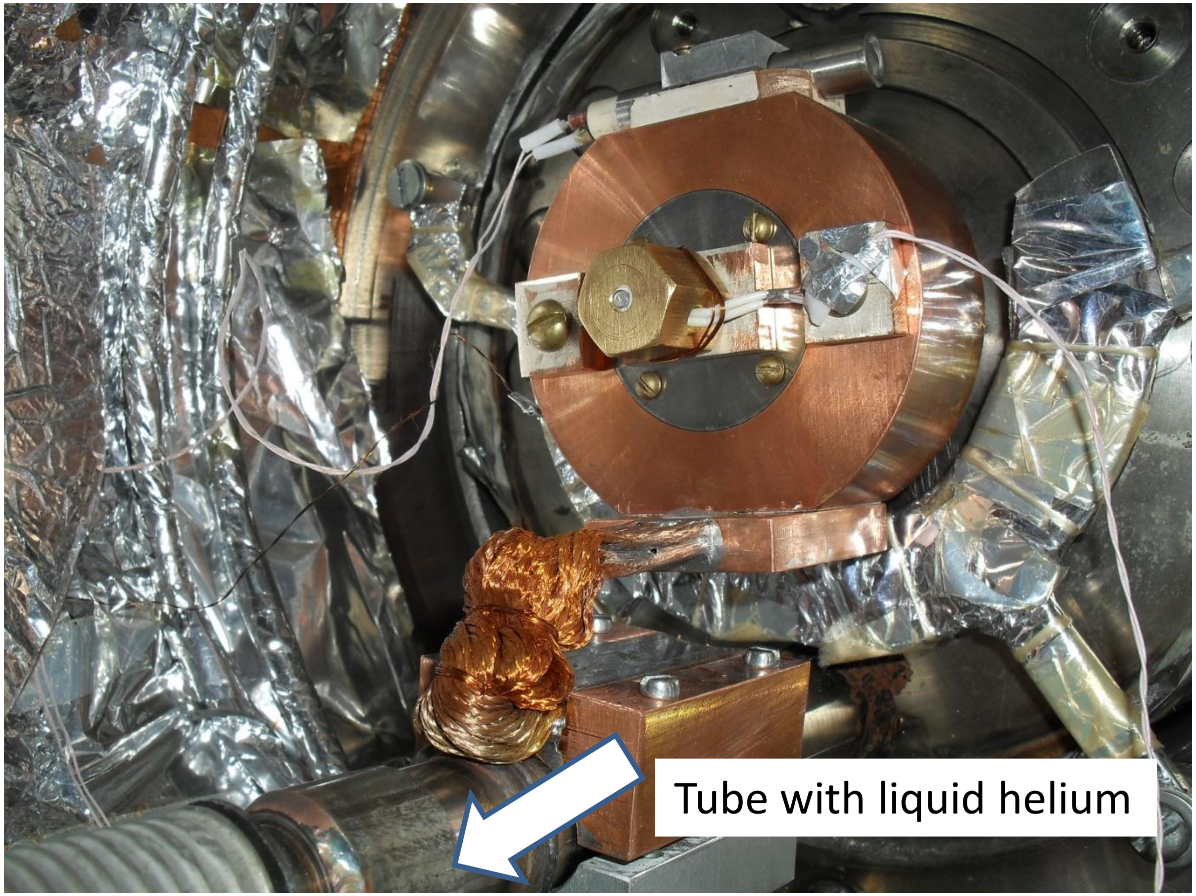
# The source with sensor and heater



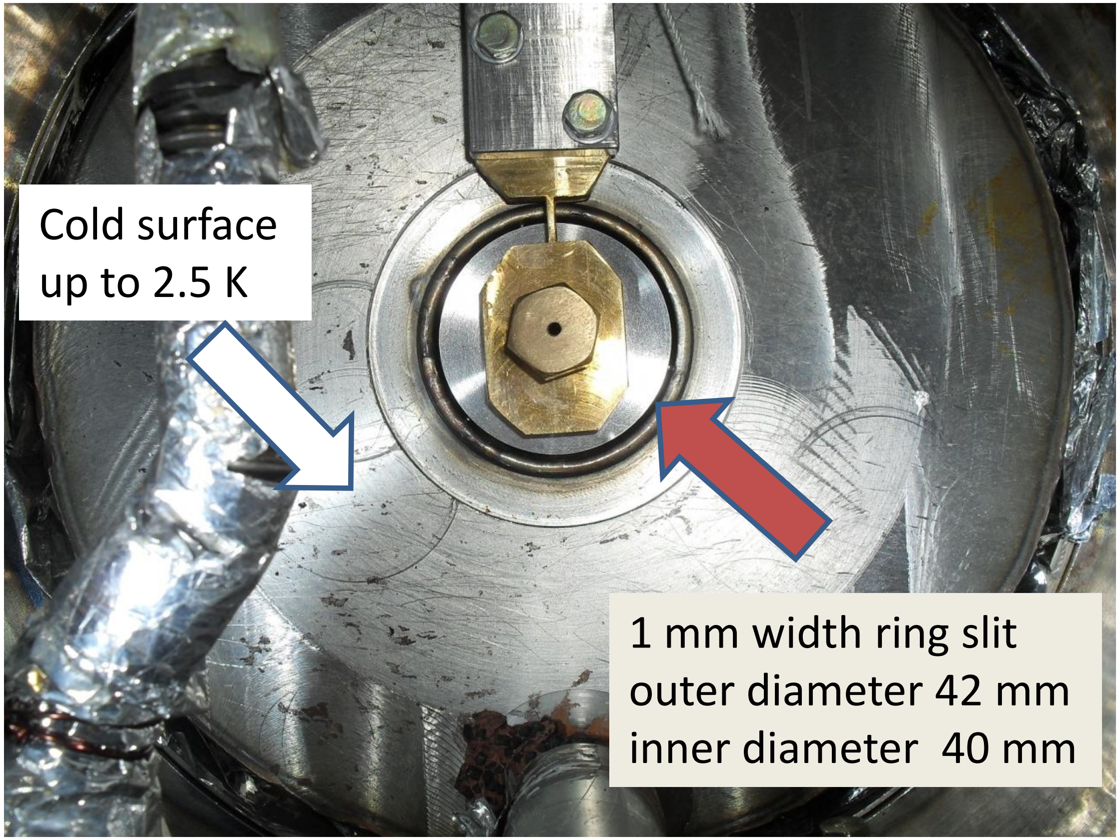
# The source with gas inlet connected



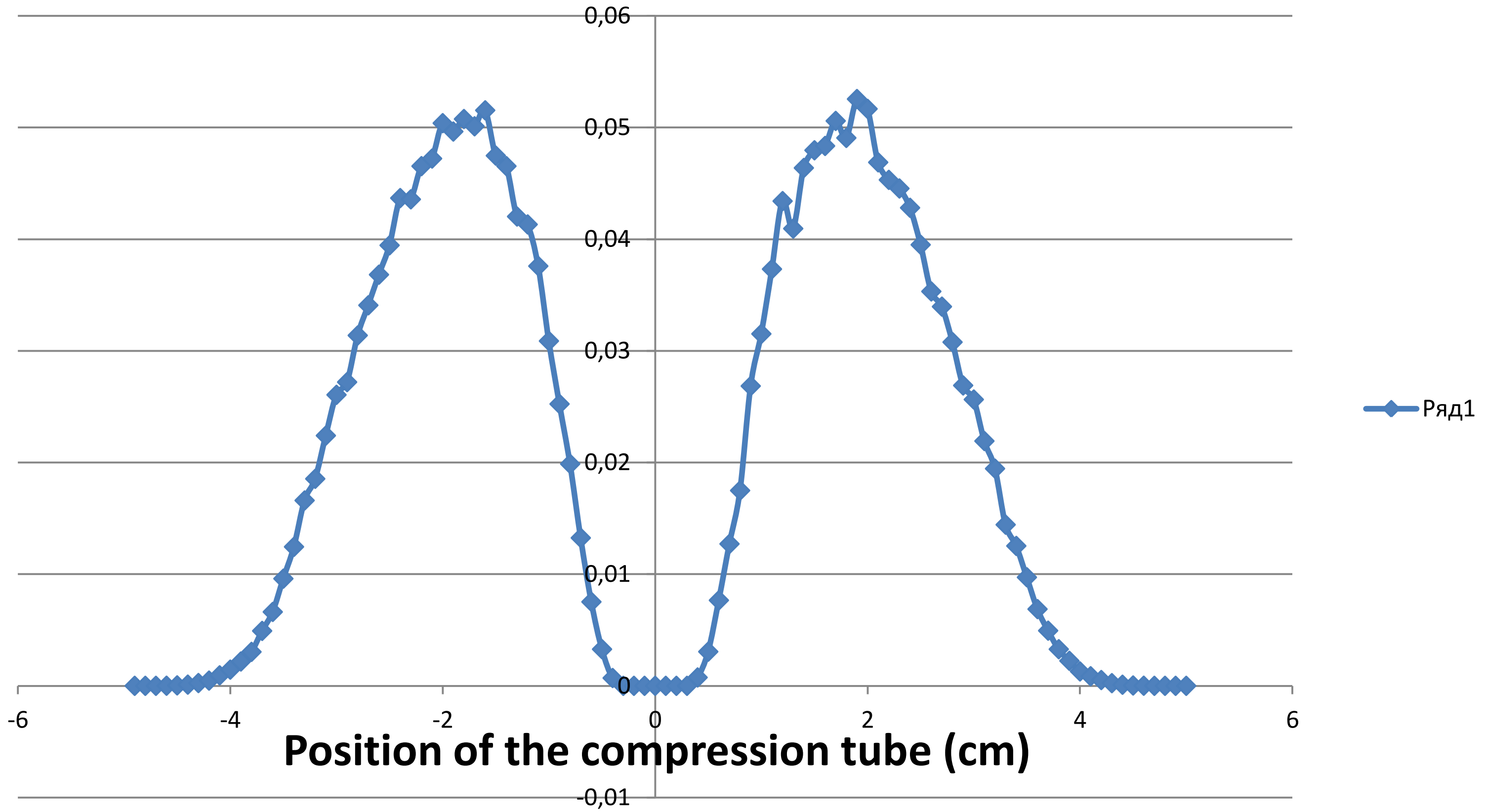
# Source installed inside the ABS



# The entrance slit of a focusing magnet



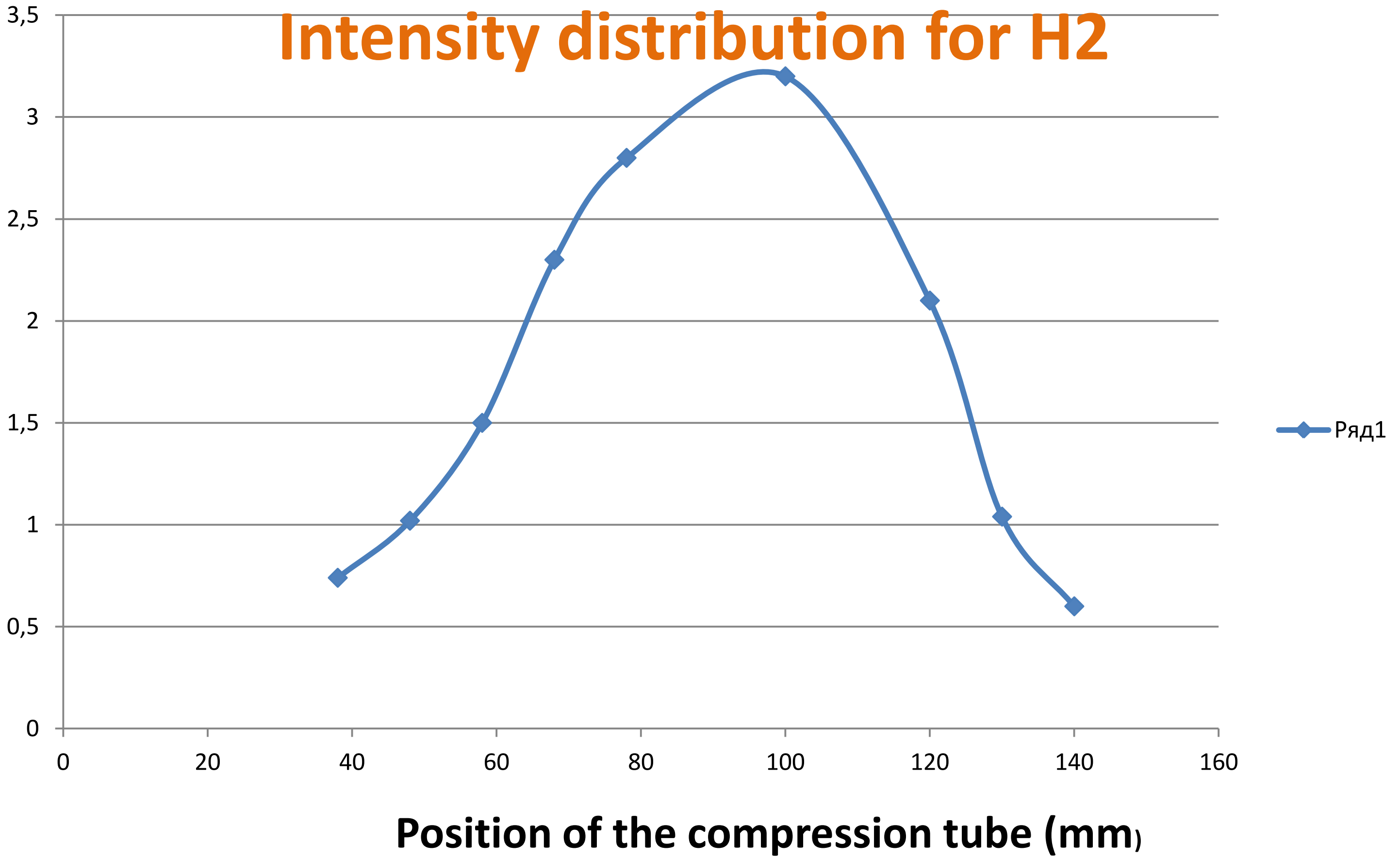
# Simulation of the molecular flux into compression tube



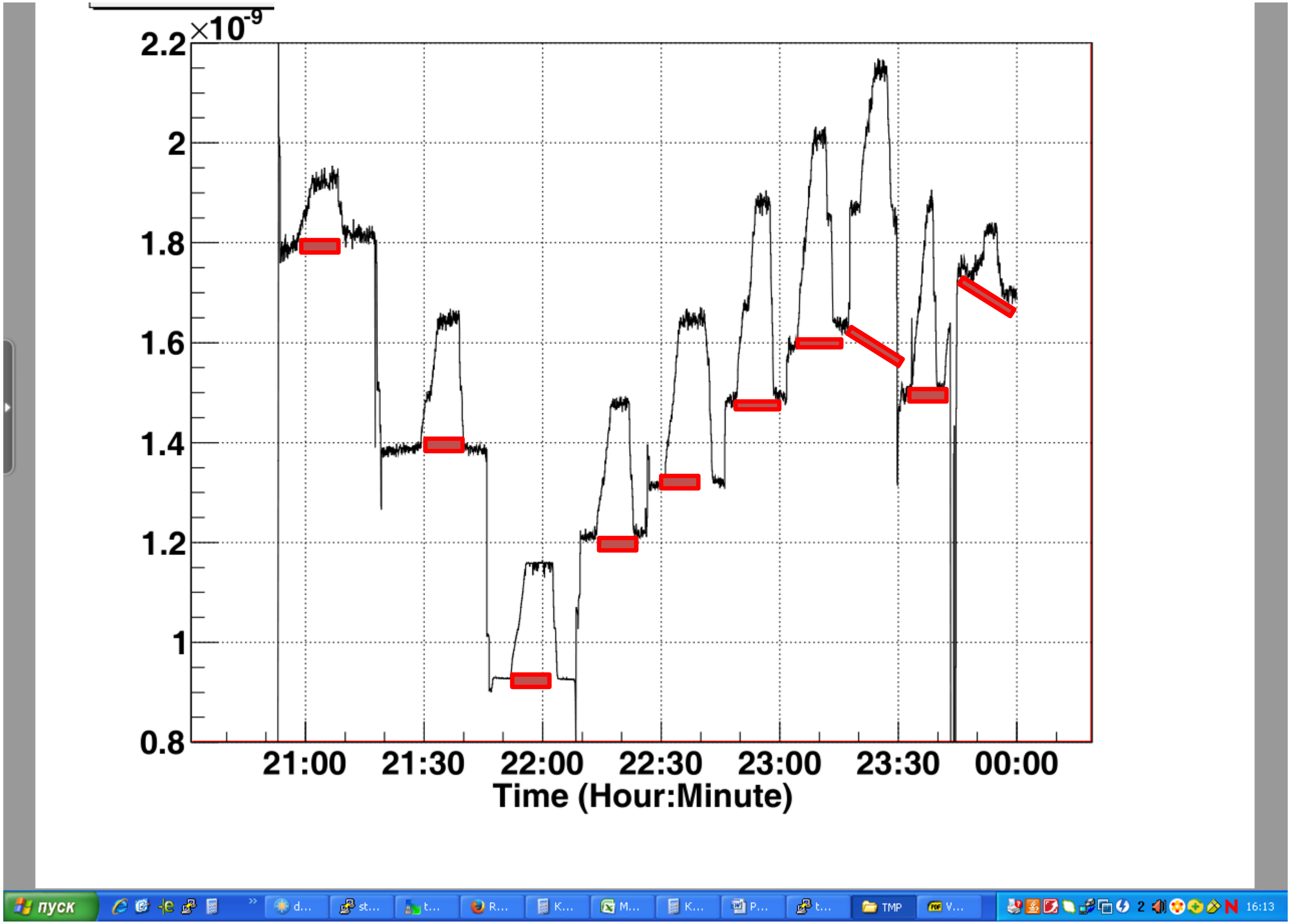

**In the assumption that molecules heat the cold surface are pumped no beam intensity should be measured by the compression tube placed at the beam axis**

## Experimental result on measurement of the molecular flux into compression tube (pressure inside the tube).

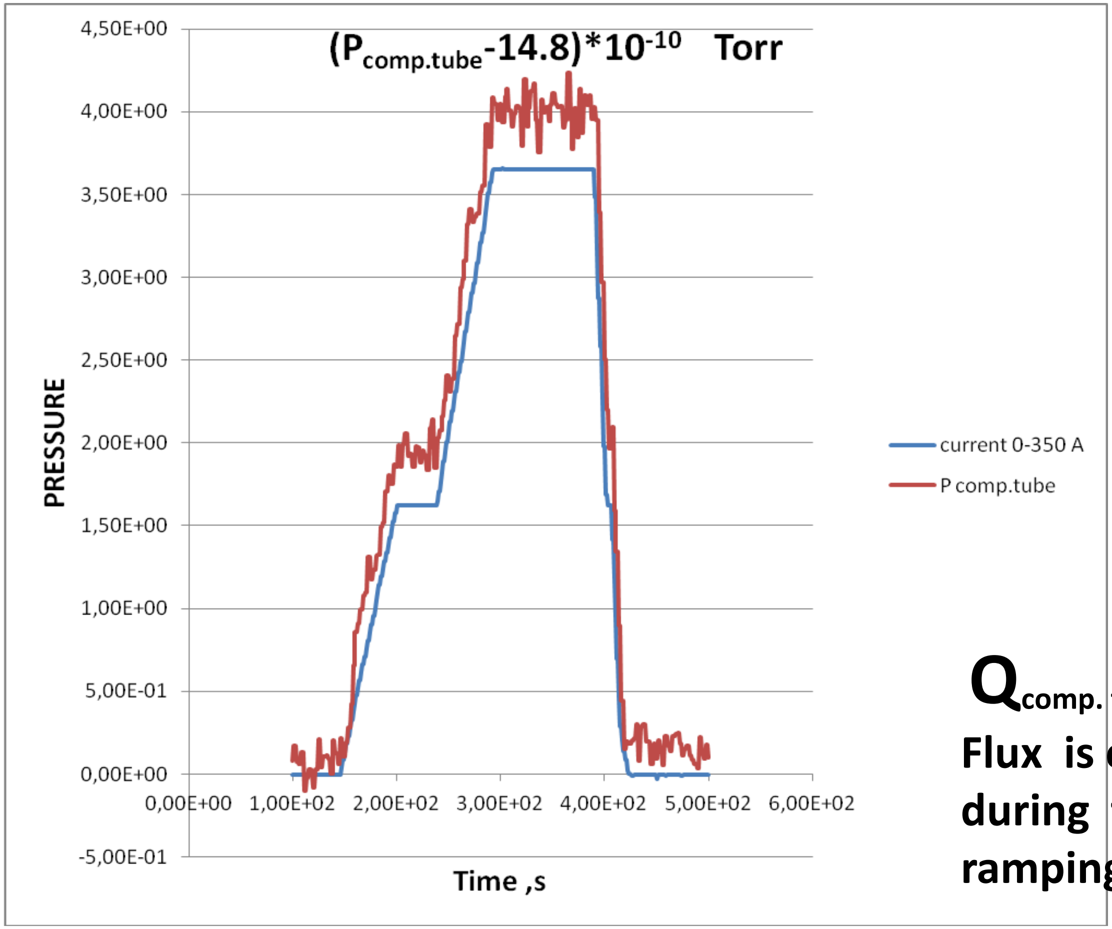
**Nothing similar to what we expected.**



# Vacuum changing in the compression tube while ramping of the magnets for different position of the compression tube



# Flux of the hydrogen molecules (pressure) into compression tube and the current through the coils of the focusing magnet

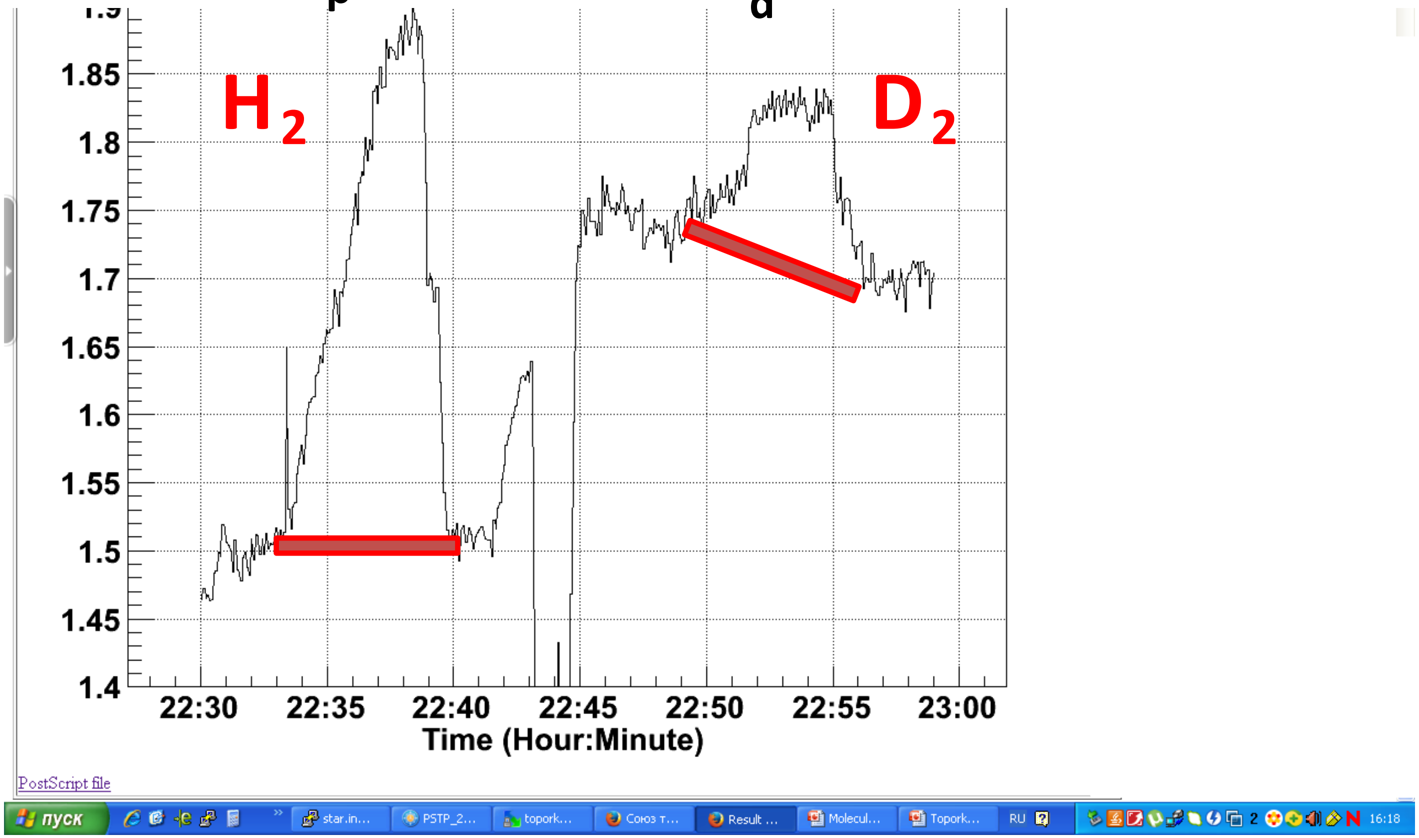



**$Q_{comp.\ tube} = 1.9*10^{12}$ mol/s**

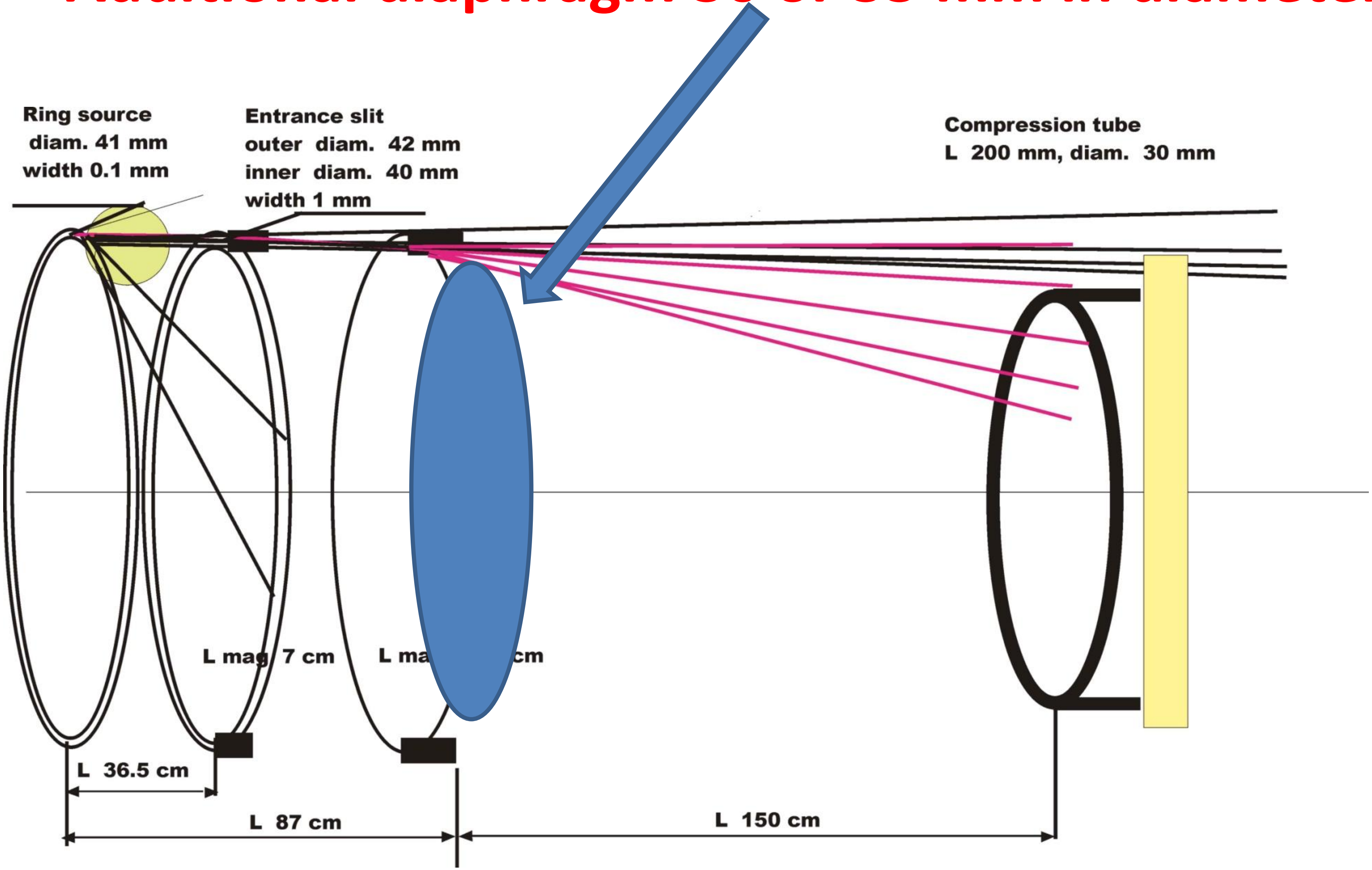
**Flux is estimated by pressure rise during the magnetic field is ramping**

# Comparison of the focusing efficiency for hydrogen and deuterium molecules

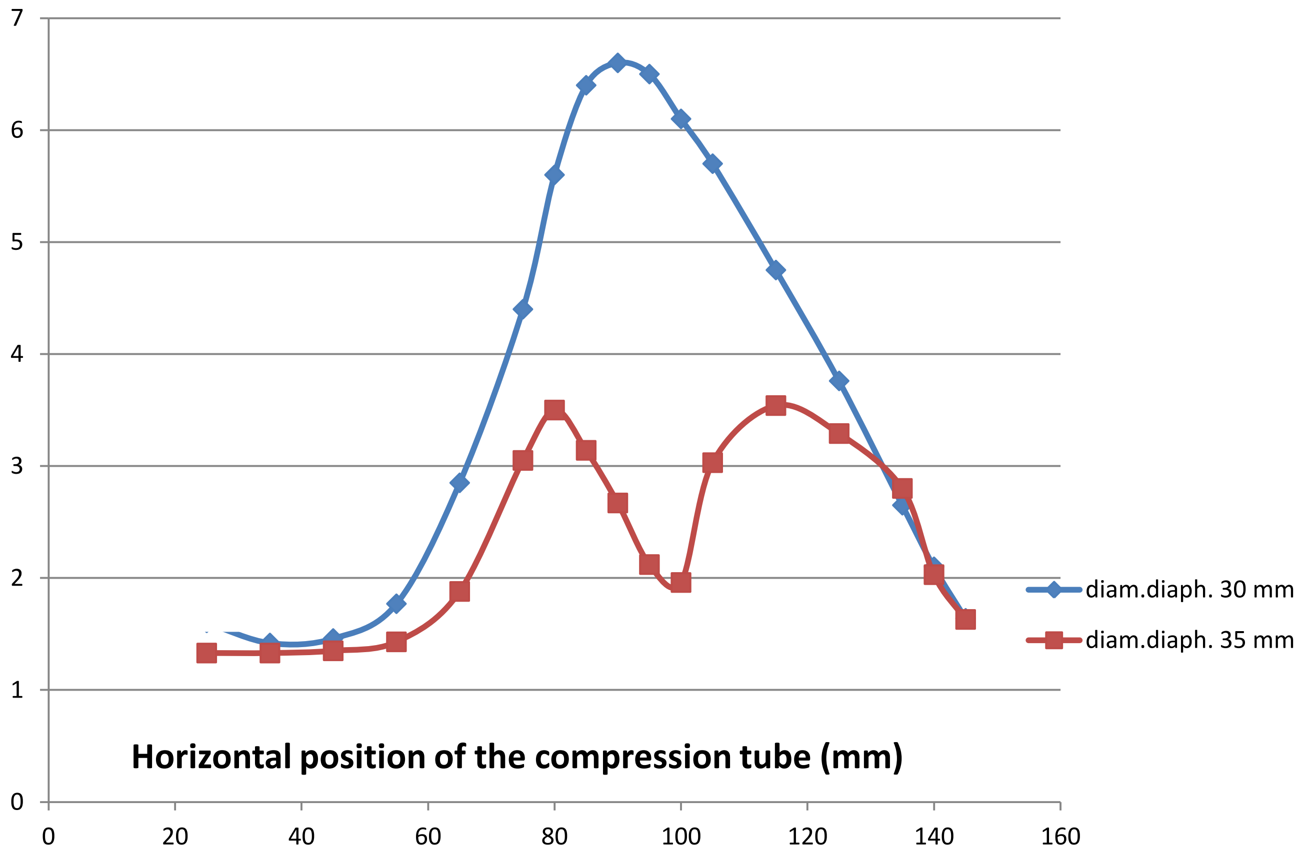
$\mu_p = 1.4 * 10^{-26}$ J/T $\mu_d = 0.43 * 10^{-26}$ J/T



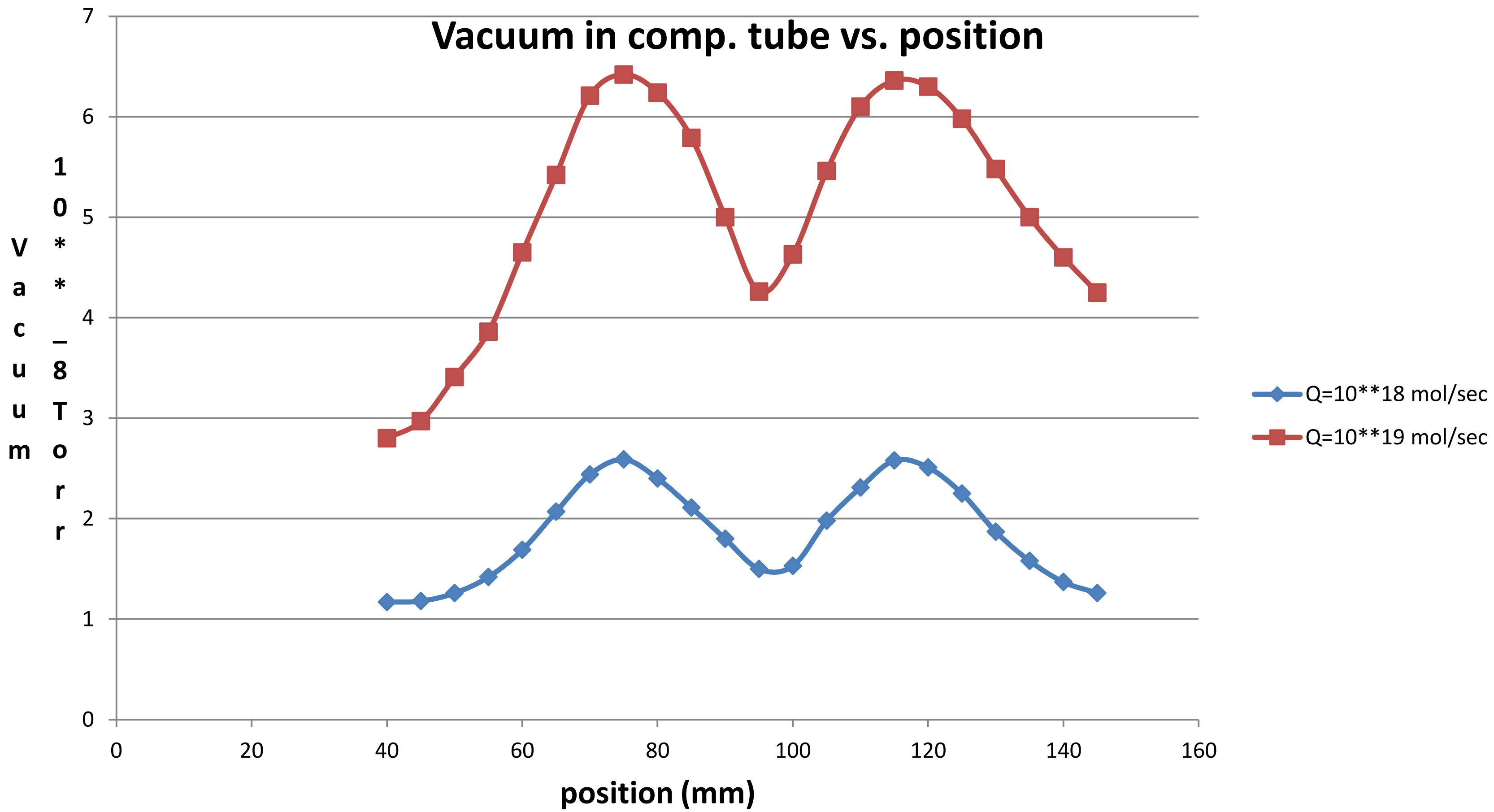
# Additional diaphragm 30 or 35 mm in diameter



# $CO_2$ beam profile measured with additional diaphragms

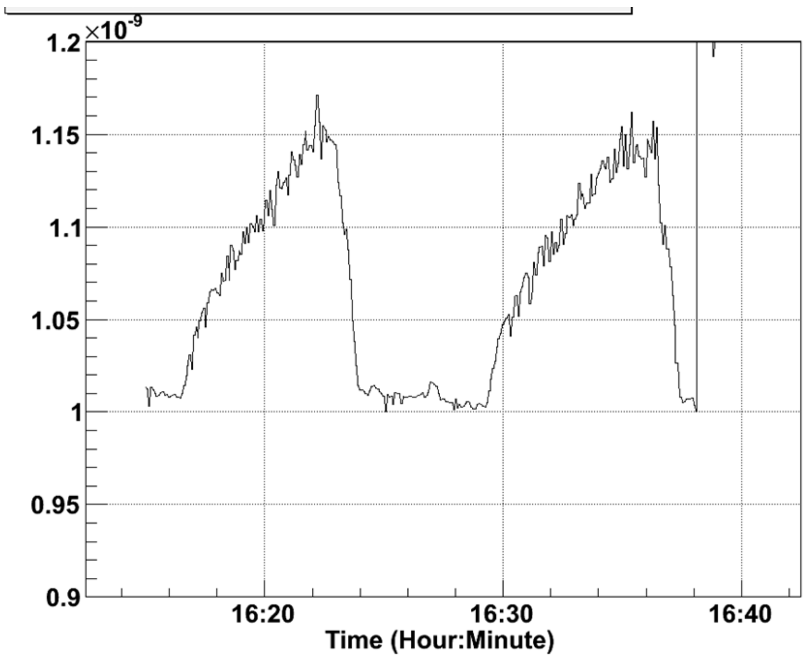


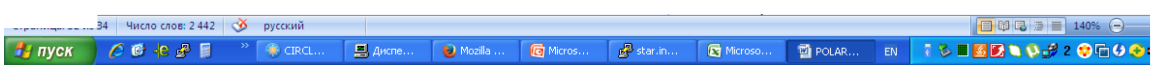
# $CO_2$ beam profile measured with additional diaphragm



# Vacuum changing in the compression tube while ramping of the magnets (hydrogen beam)

## (tube in a center position)



# Monte Carlo simulation

**Maxwell–Boltzmann velocity distribution at 9 K for hydrogen**

**Cos($\theta$) intensity distribution from the source**

**Flux of focused molecules into the compression tube**

$$Q_{comp.\ tube} = 0.9*10^{-6}\ Q_{nozzle}$$

**Experiment (comp. tube in a beam axis)**

$$Q_{comp.\ tube} = 0.8*10^{-6}\ Q_{nozzle}$$

$$Q_{comp.\ tube} = 0.7*10^{12}\ \text{mol/s}$$

$$Q_{nozzle} = 8.6*10^{17}\ \text{mol/s}$$

# Future prospect

- Measurement of the polarization of molecules using Lamb-shift polarimeter
- Directivity of the molecular beam
- Understanding the process of molecules reflection from the cold surface
- Design prototype of a new source

# Conclusion

- The measured flux of focusing molecules is close to the expected one
- **More investigation should be done to get optimal molecular flux from the CABS**
- This and further investigation will be done under the joint RSF-DFG grants № 16-42-01009 and № BU 2227/1-1

***THANK YOU !***