Status of polarized molecular source

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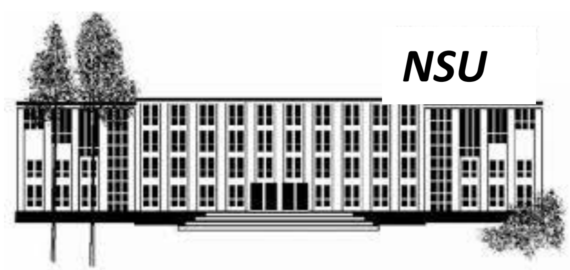
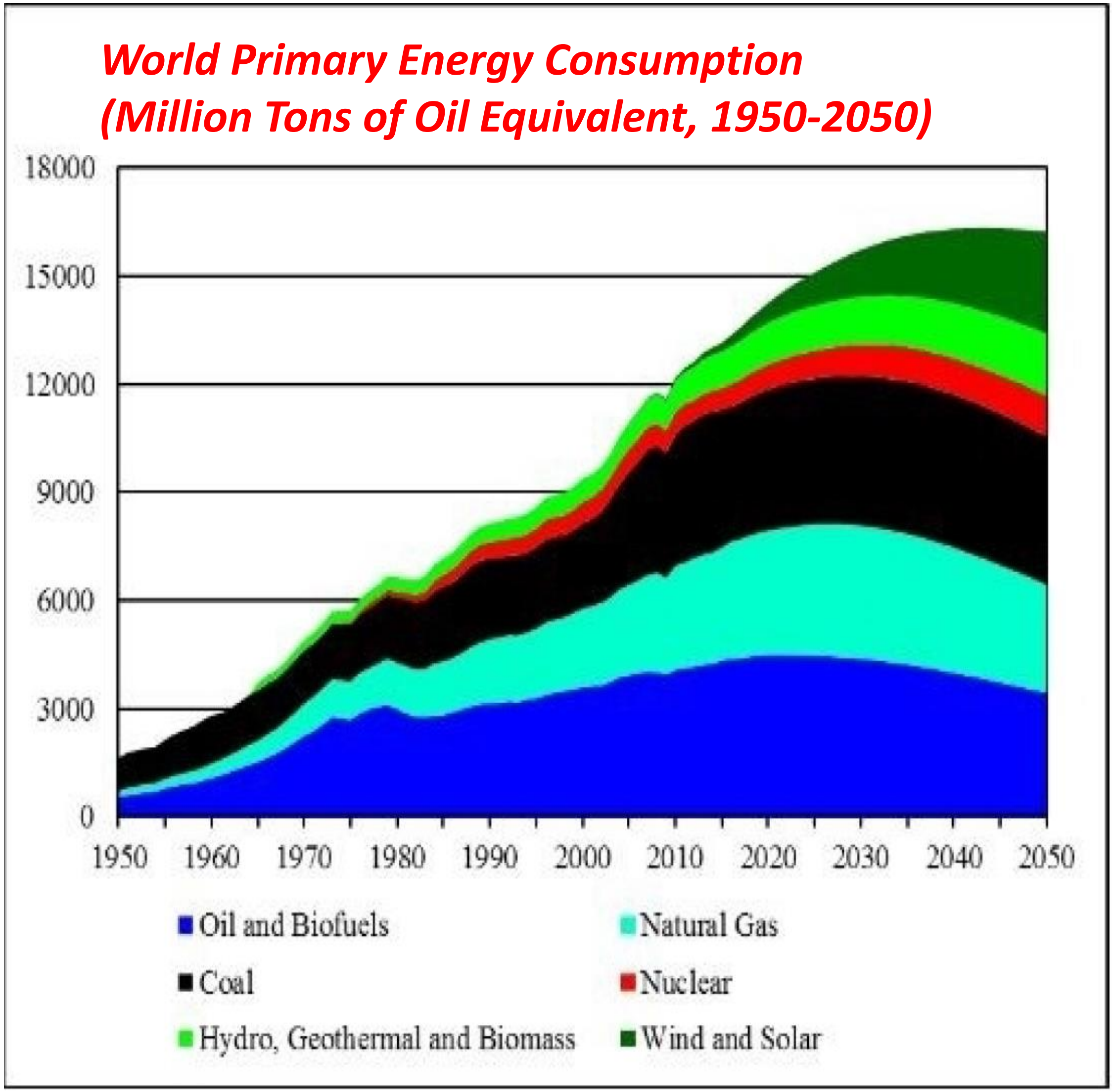
BINP

NSU





~ 20 Tw up to now

- Patterson, R. (2016) World Energy 2016-2050: Annual Report. http://peakoilbarrel.com/world-energy-2016-2050-annual-report/

The most important thermonuclear reactions

Reaction	σ_m(b)	E_m(keV)
$D + T \rightarrow n(14.1) + {}^4He(3.5)$	5.0	107
$D + D \rightarrow \begin{cases} n(2.45) + {}^3He(0.85)\ 50\% \\ p(3.02) + T(1.01)\ 50\% \end{cases}$	0.1 0.1	1500 1500
$D + {}^3He \rightarrow p(14.7) + {}^4He(3.6)$	0.71	430

Full polarization of the deuteron and He^3 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

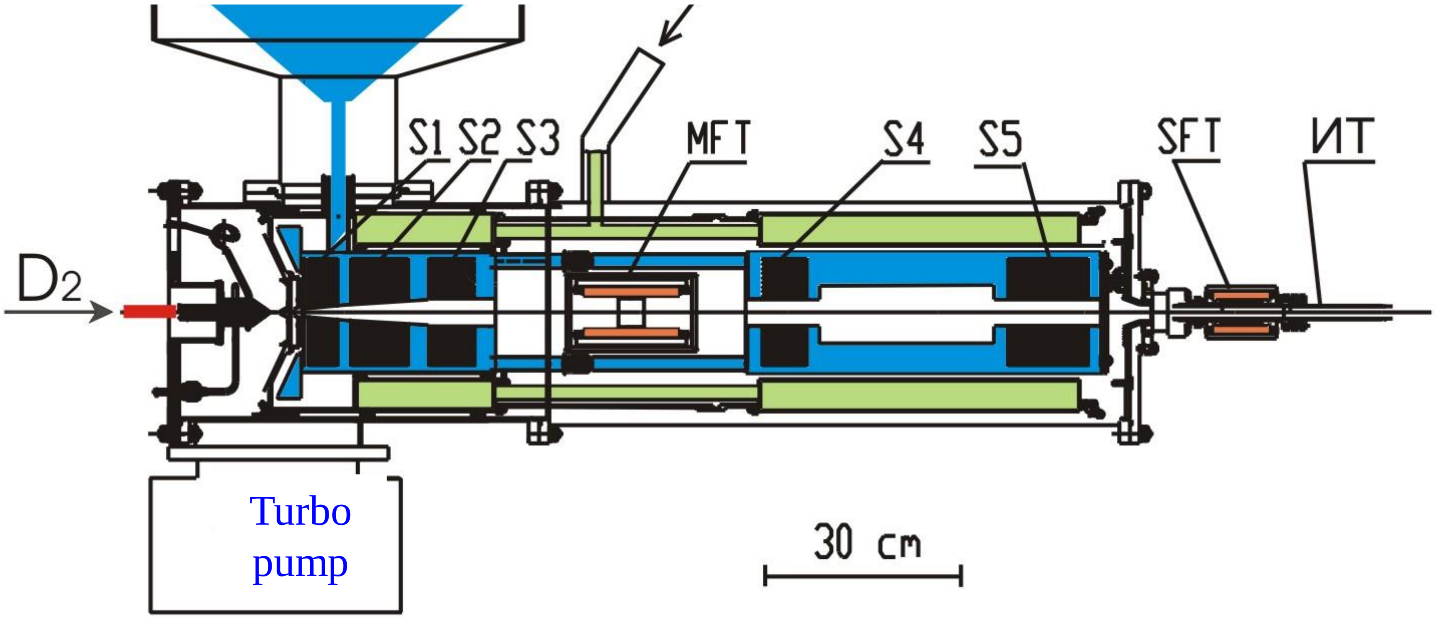
The sources of polarized atoms (ABS) has been developed from the early 50th. Clausnitzer was the first who got a polarized proton beam using an ABS with quadrupole focusing magnets. The intensity of polarized atomic beam was approximately 10^{11} at/sec.

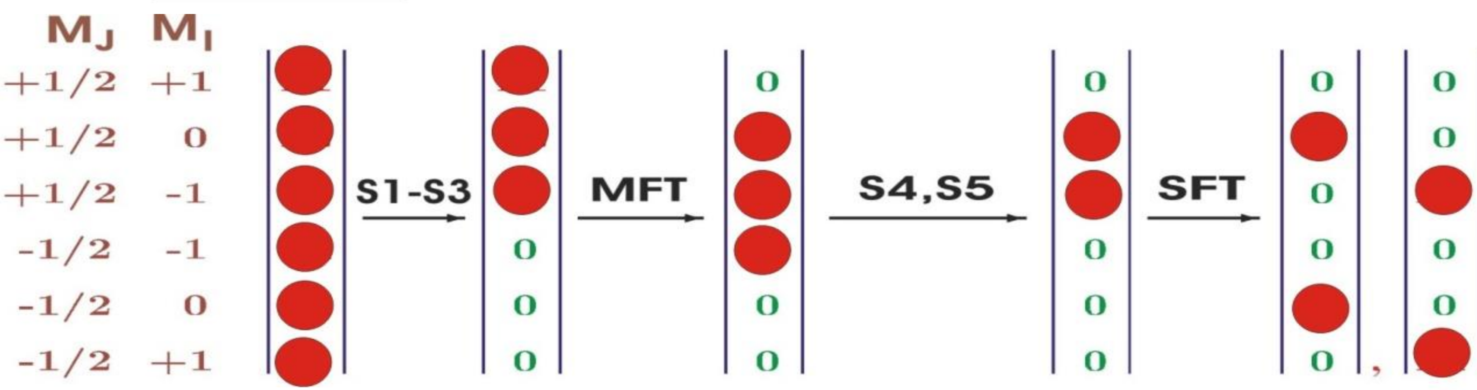
[G. Clausnitzer, R. Fleischman, H. Shopper, Zs. F. Physik 144 (1956) 336]

R. L. Garwin. Rev. Sci. Instrum. 29 (1958) 374.

Since there fast developing of this technique now reached the limit in the intensity of polarized atoms. The best sources deliver about 10^{17} at/sec

Novosibirsk Cryogenic Atomic Beam Source

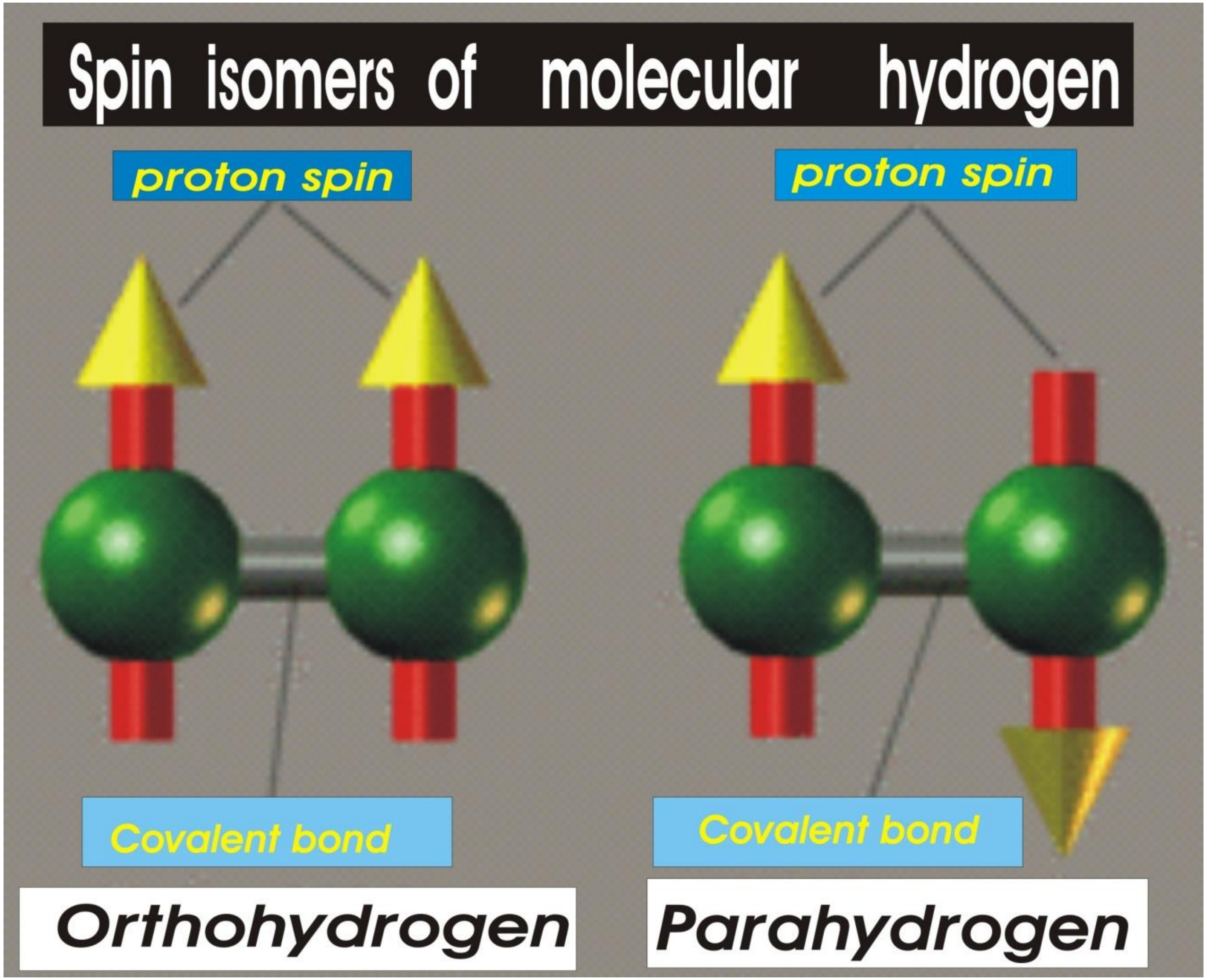




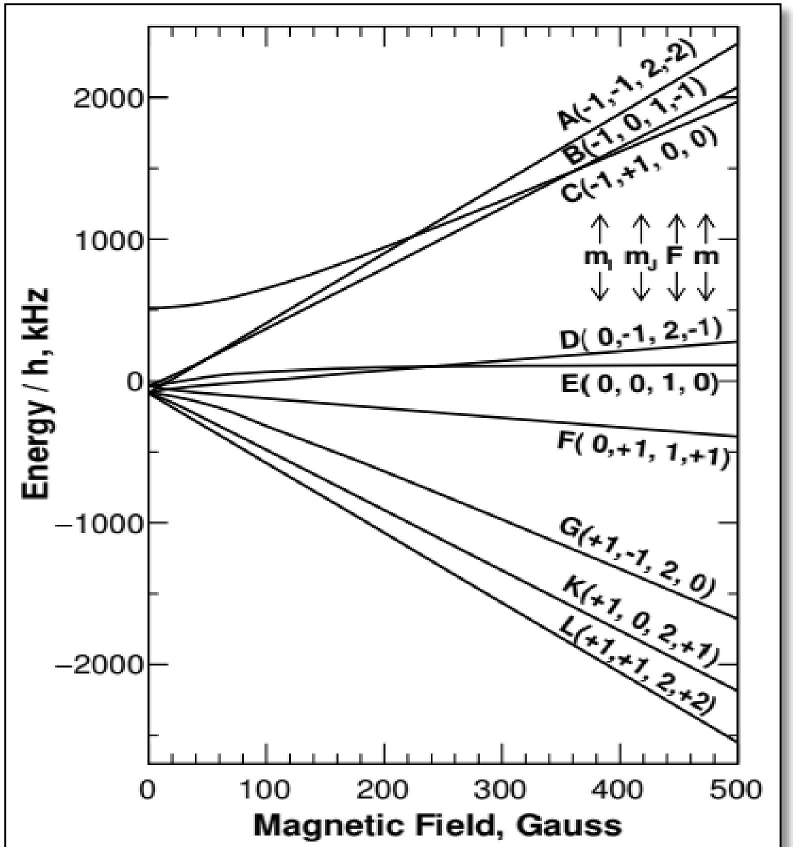
Tensor polarization $P_{zz} = 1 - 3n_0 = -2, +1.$

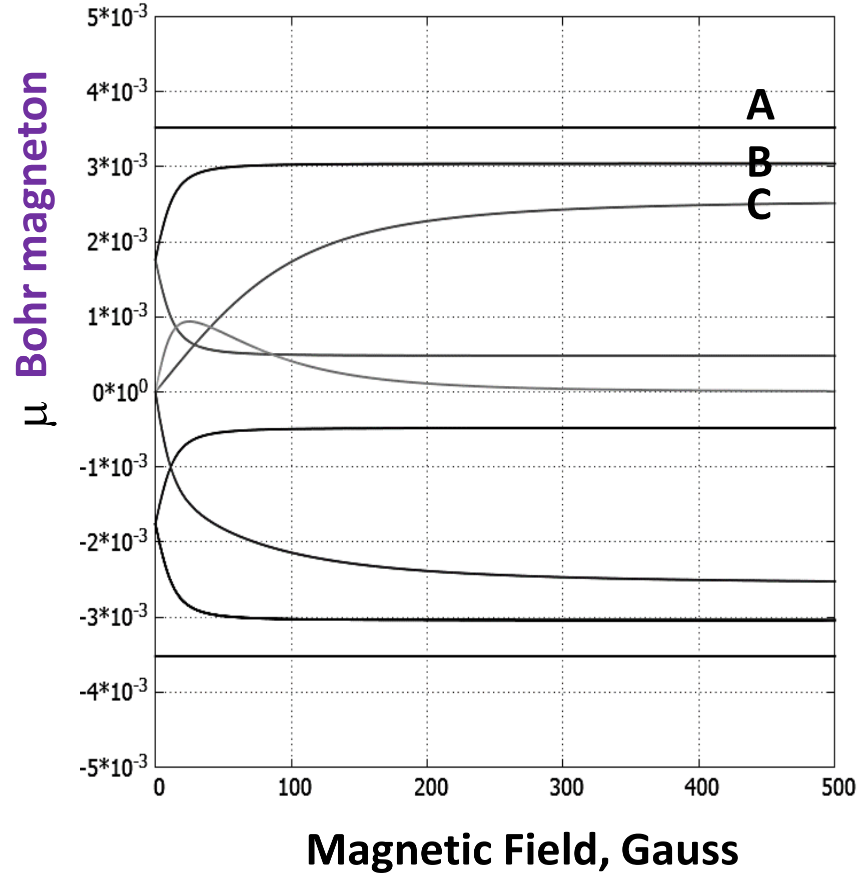
Vector polarization $P_z = n_+ - n_- = 0.$

Ortho and parahydrogen



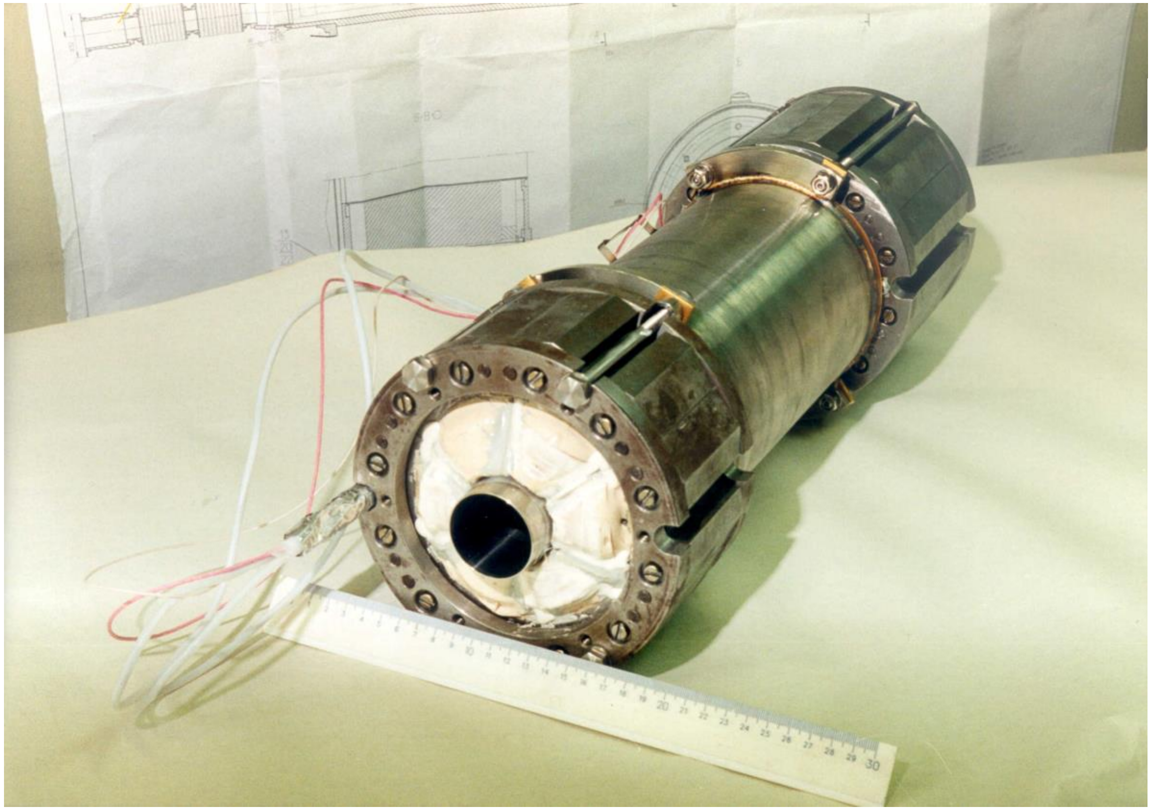
Energies of H_2 states as a function of magnetic field.

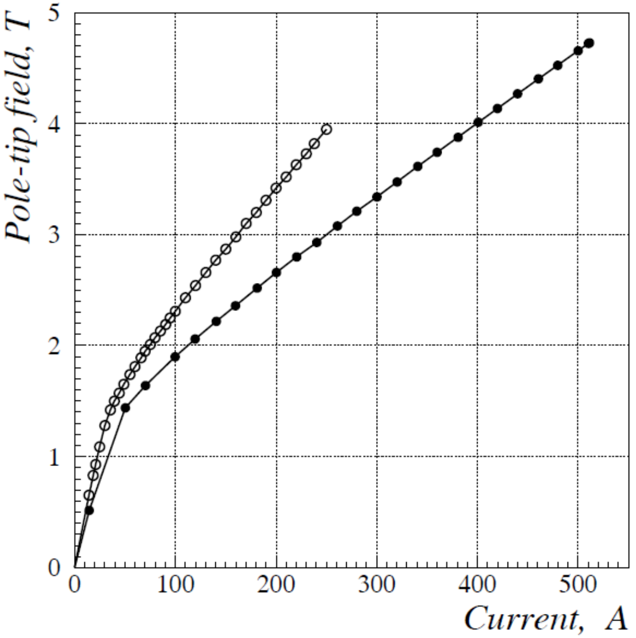




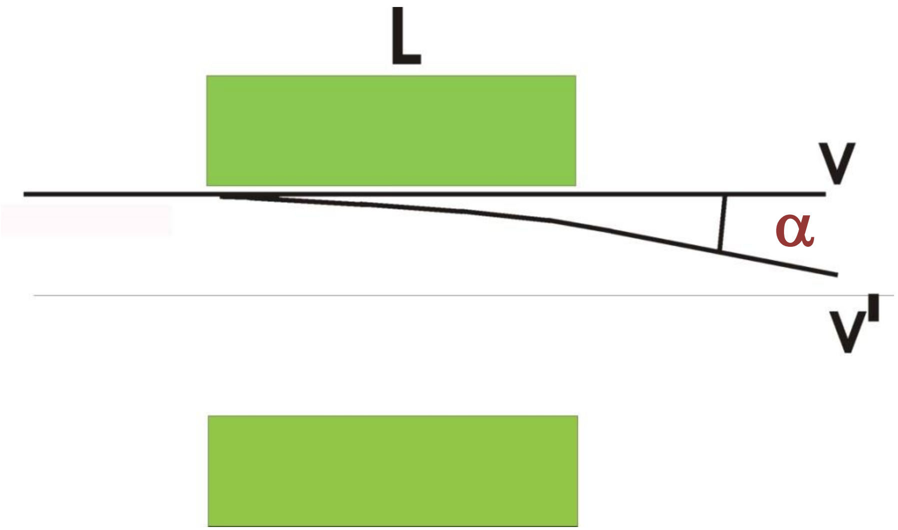
Only molecules in the states A, B, C with m_I=-1, which are focused by the field can enter the CT.

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





Geometry selection



$$F = m\ddot{r} = -\nabla W = \mu\cdot\partial B/\partial r = C$$

$$\dot{r} = \upsilon_r = C\cdot t/m\upsilon$$

$$t = L/\upsilon$$

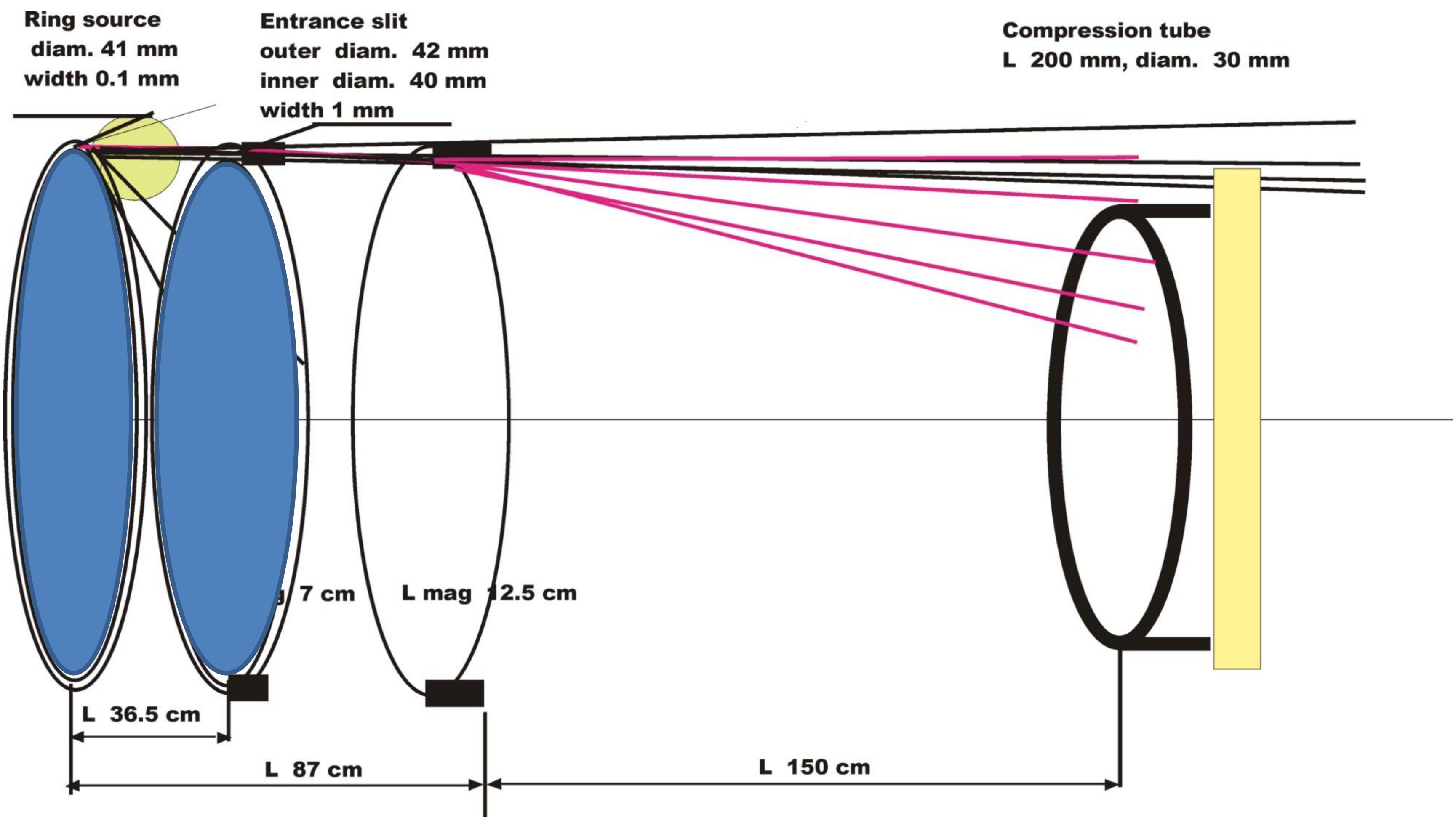
$$\upsilon_r = C\cdot L/(m\cdot\upsilon)$$

$$\alpha = \upsilon_r/\upsilon = C\cdot L/(m\cdot\upsilon^2)\approx C\cdot L/(k\cdot T$$

For our case $\mu = \mathbf{2.5}\ 10^{-3}\ \mu_B$, $T \approx 8K$, $L=19.5$ cm, $\partial B/\partial r = 32$ kG/cm,

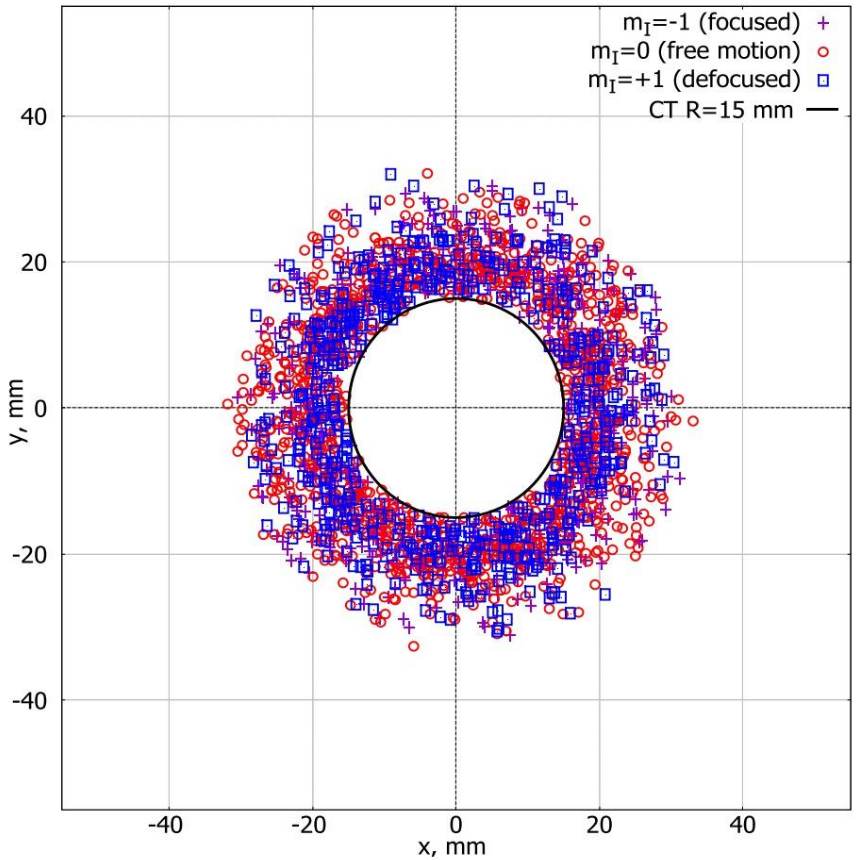
$$\alpha = 1.3\cdot 10^{-3}\ \text{rad}$$

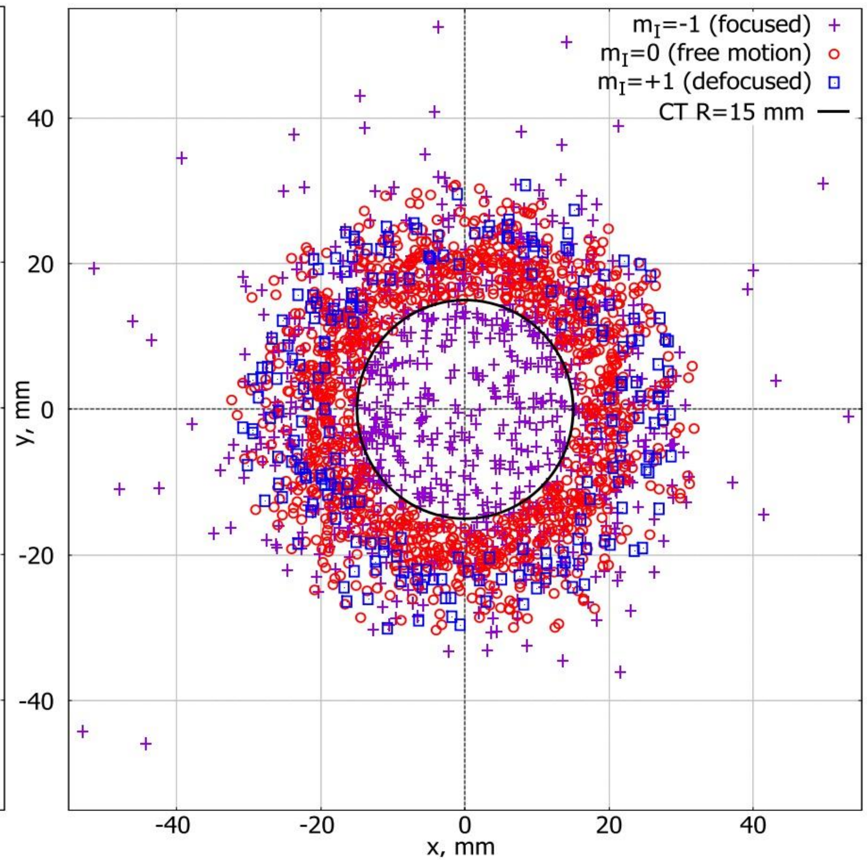
Polarized molecules source based on existing cryogenic ABS



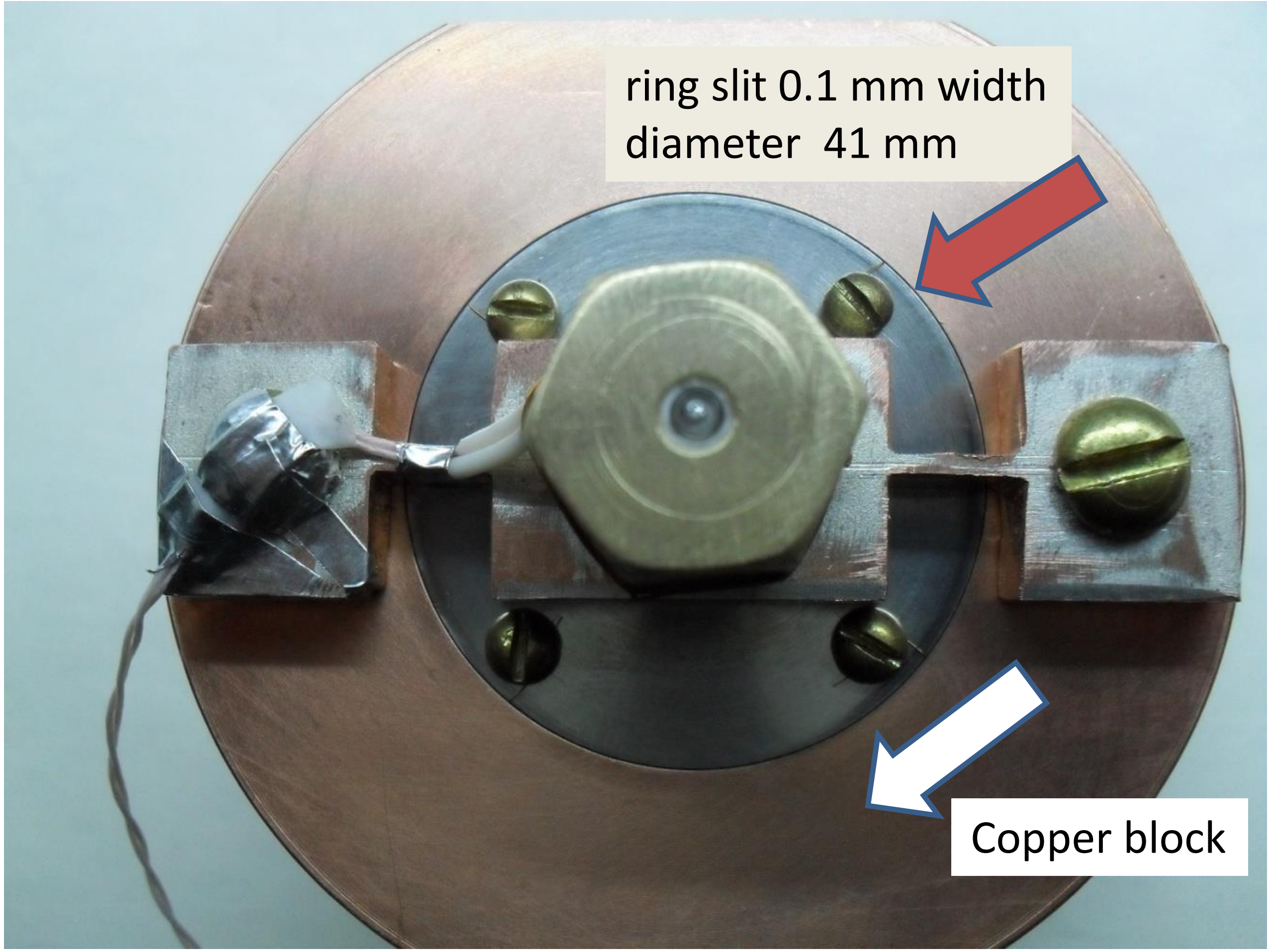
The source of polarized hydrogen molecules at the test bench

Monte Carlo simulation of the spatial distribution of the molecules at the location of the inlet receiver tube.





Source of cold hydrogen molecules



The entrance slit to a focusing magnet

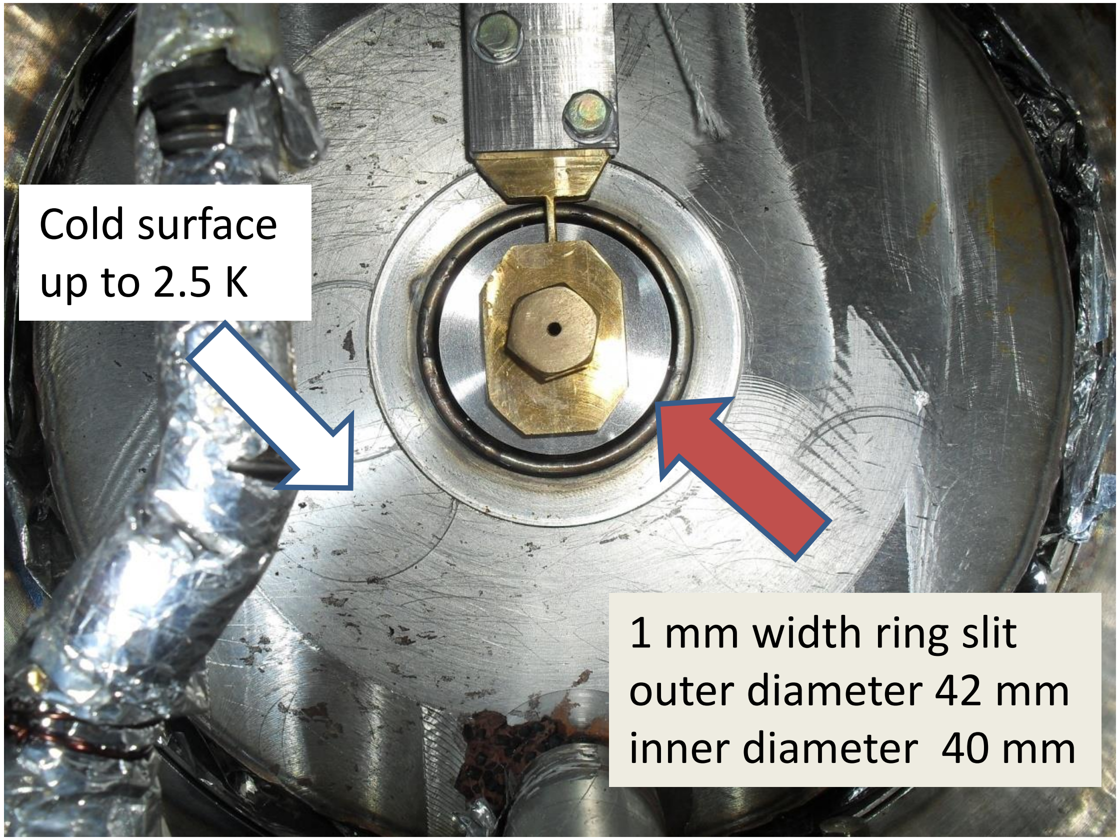
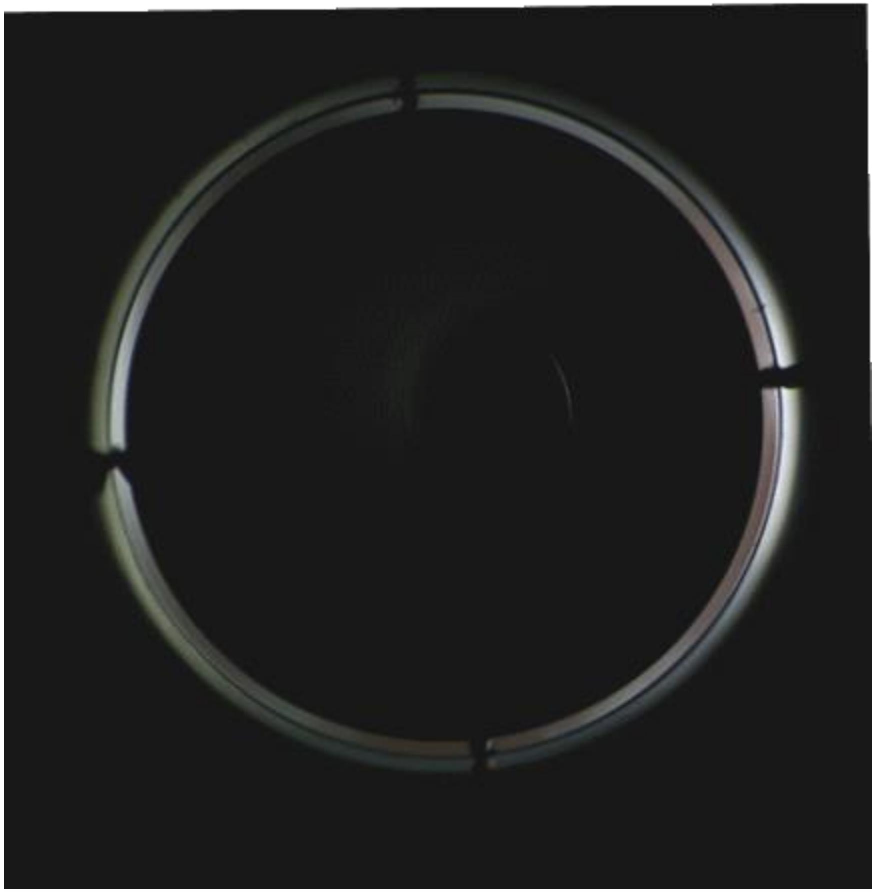
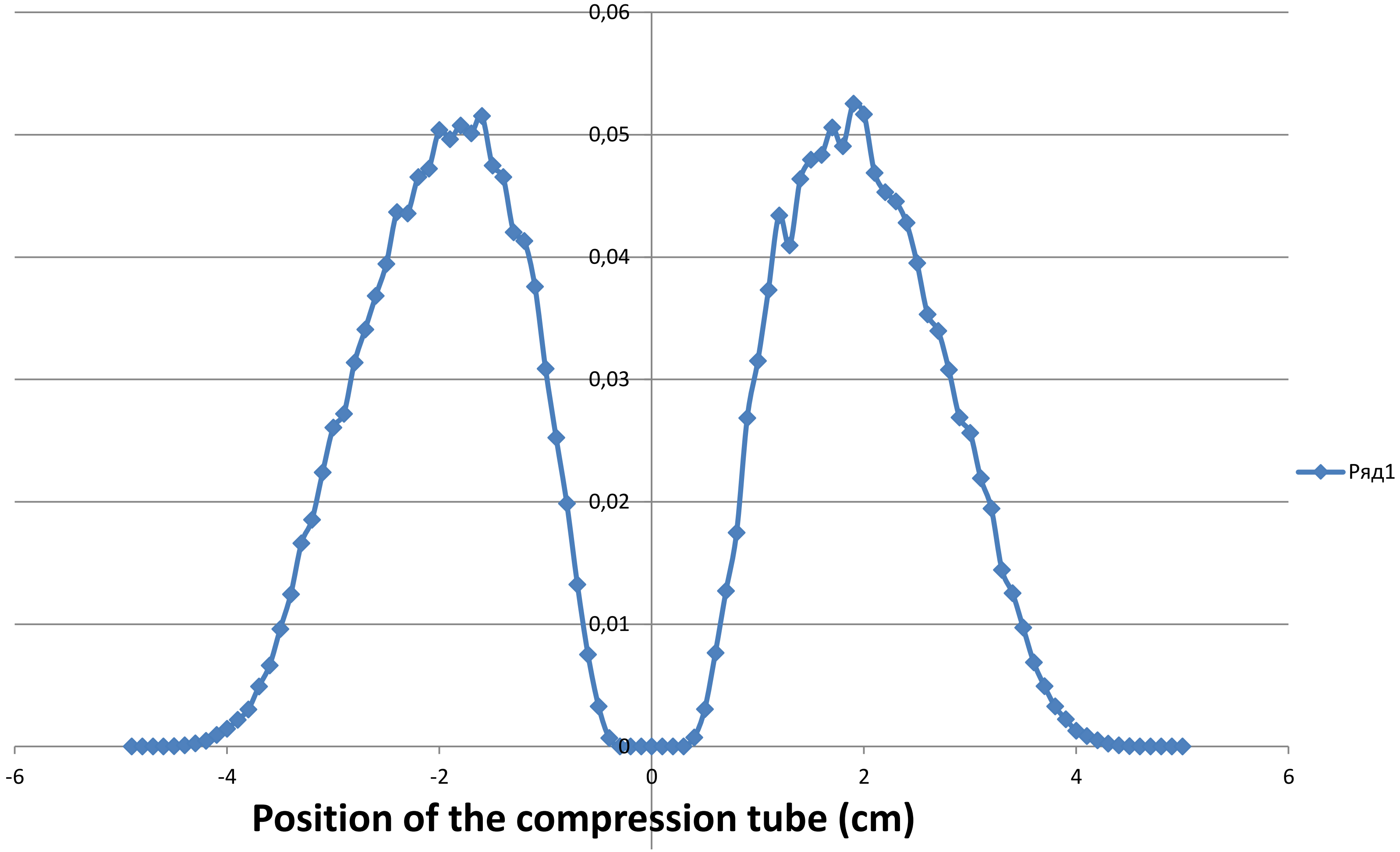


Photo of the nozzle and diaphragm made from the exit of the magnet

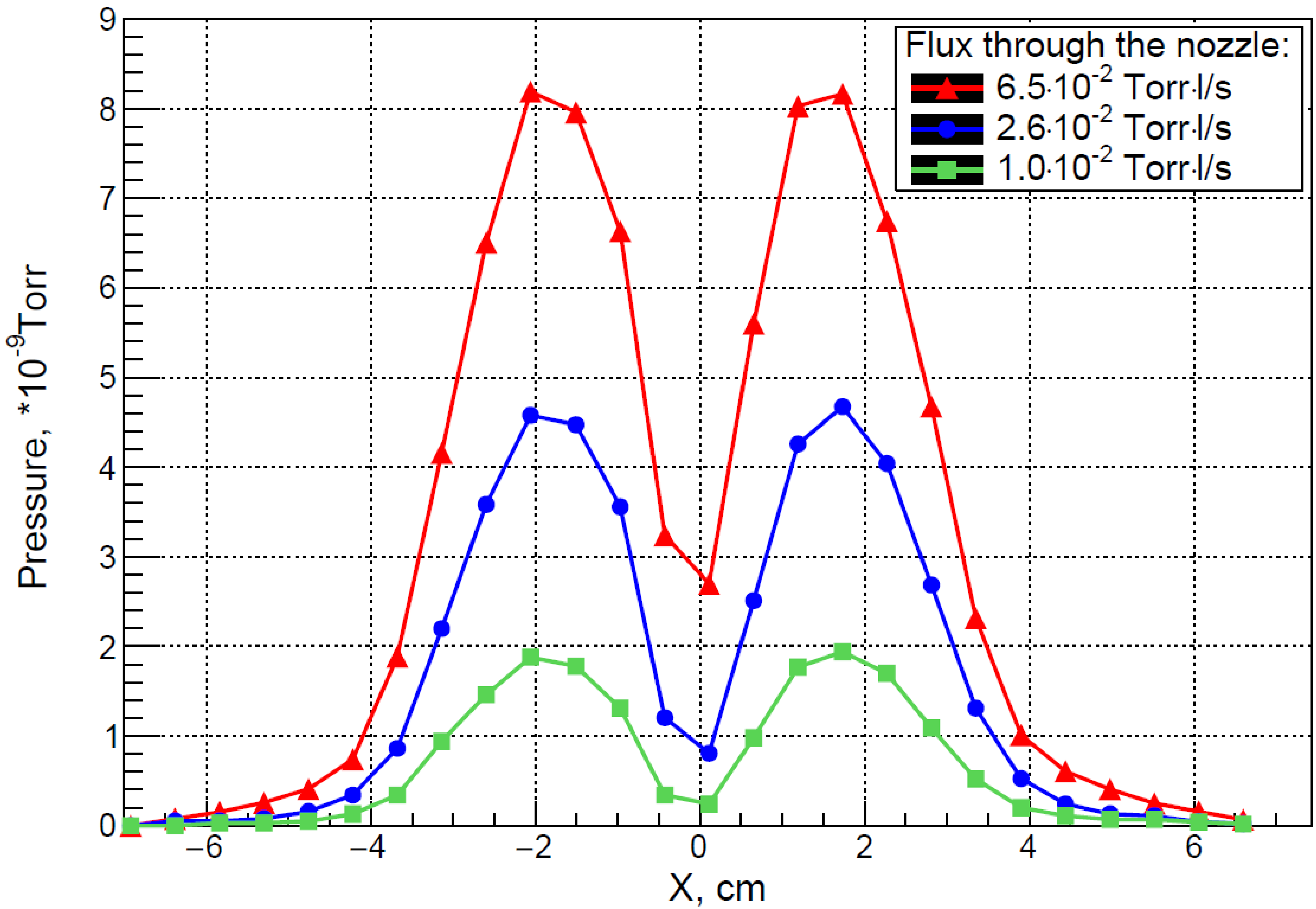


Distribution of the beam intensity measured by compression tube having a diameter 30 mm (simulation)

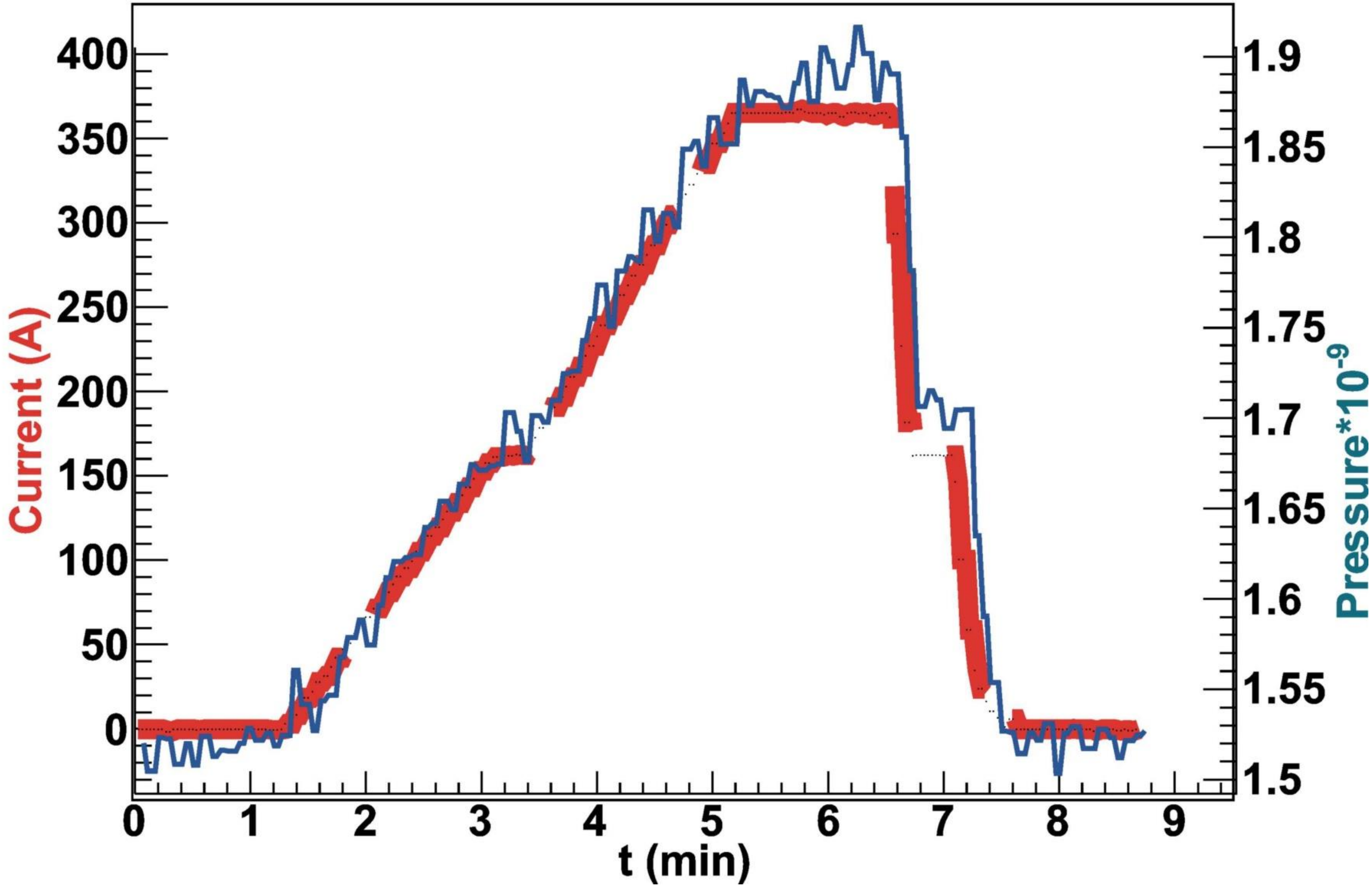


No beam intensity should be measured at the beam axis in the assumption that molecules touched the cold surface are pumped.

Profile of the molecular jet measured by the compression tube

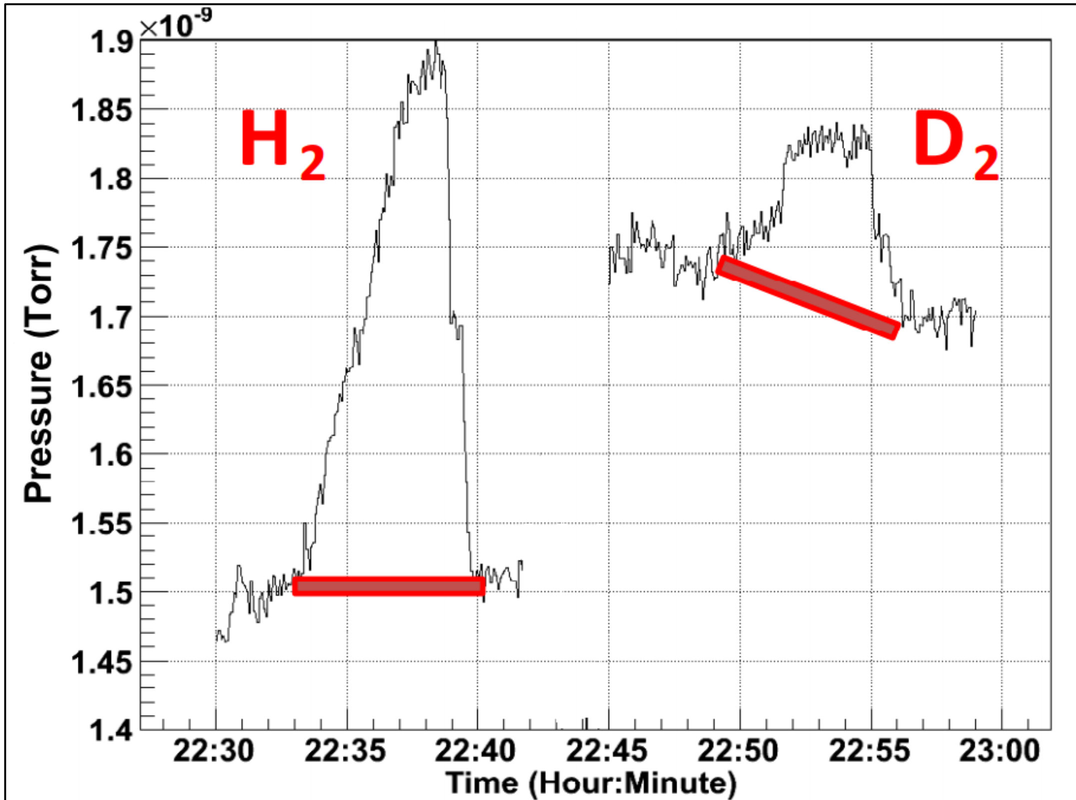


Correlation between the magnetic field and the intensity of the focused beam



Experimental results :: comparison of focusing efficiency H_2 and D_2

The flux of the focused deuterium molecules is lower since the magnetic moments of D_2 molecules are much smaller than those of H_2 molecules.

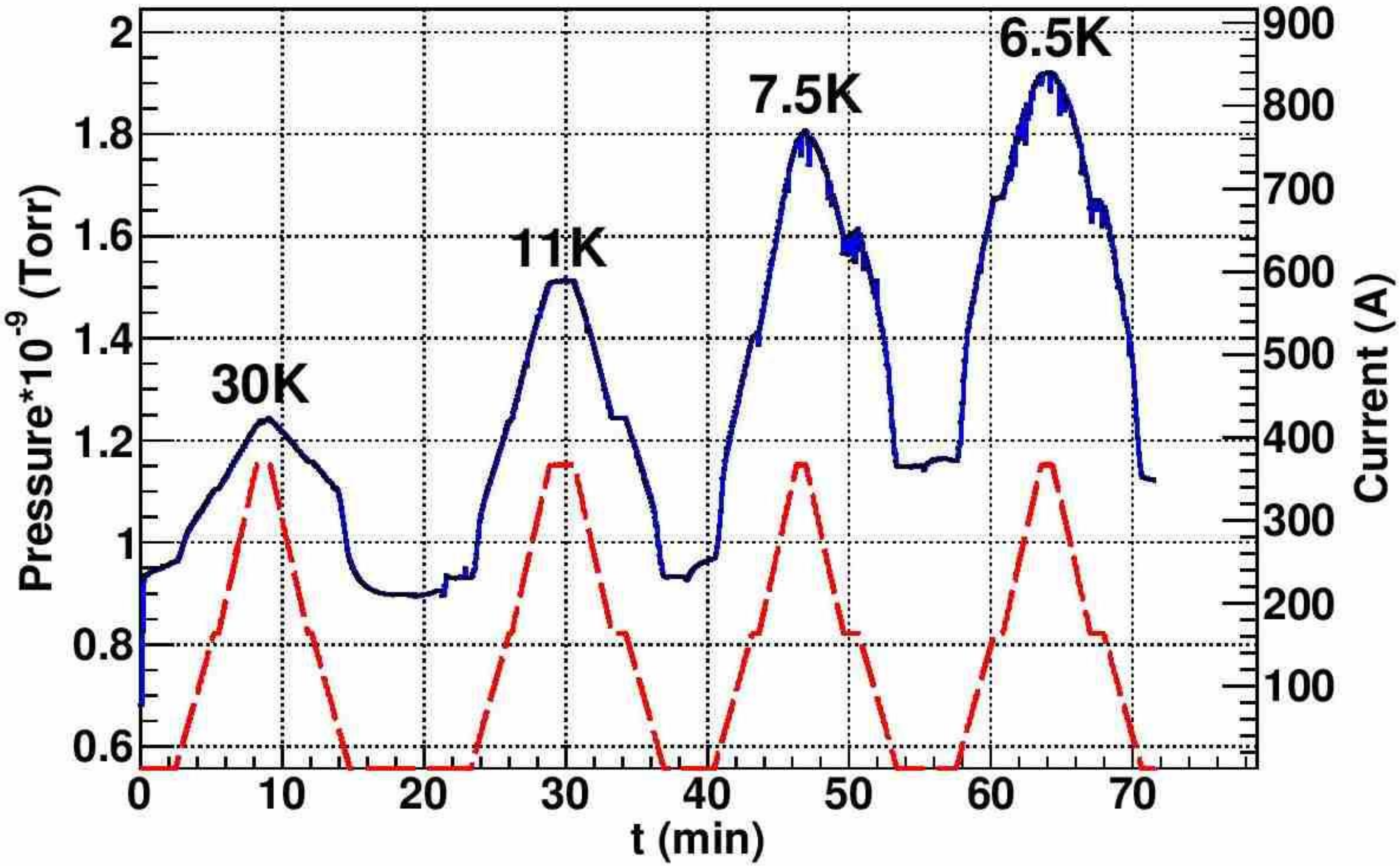


Magnetic moment of H_2 is $2.5 \cdot 10^{-3}\ \mu_B$

Magnetic moment of D_2 is $6.5 \cdot 10^{-4}\ \mu_B$

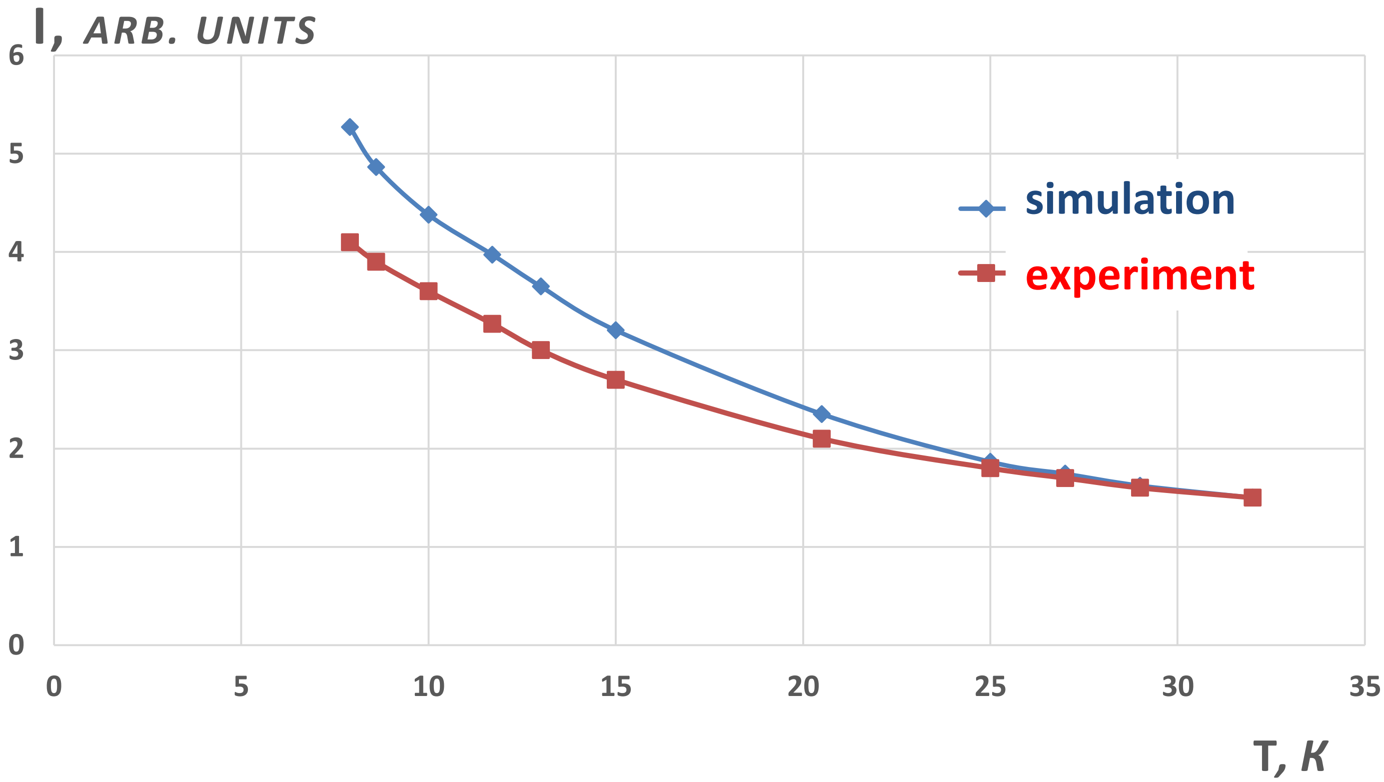
The measured flux of polarized deuterium molecules is about 7 times smaller than the flux of hydrogen molecules. The geometry of the source was not optimized to get the highest flow of D_2.

Intensity of the H2 beam while ramping the magnet for different nozzle temperature (computer screen)

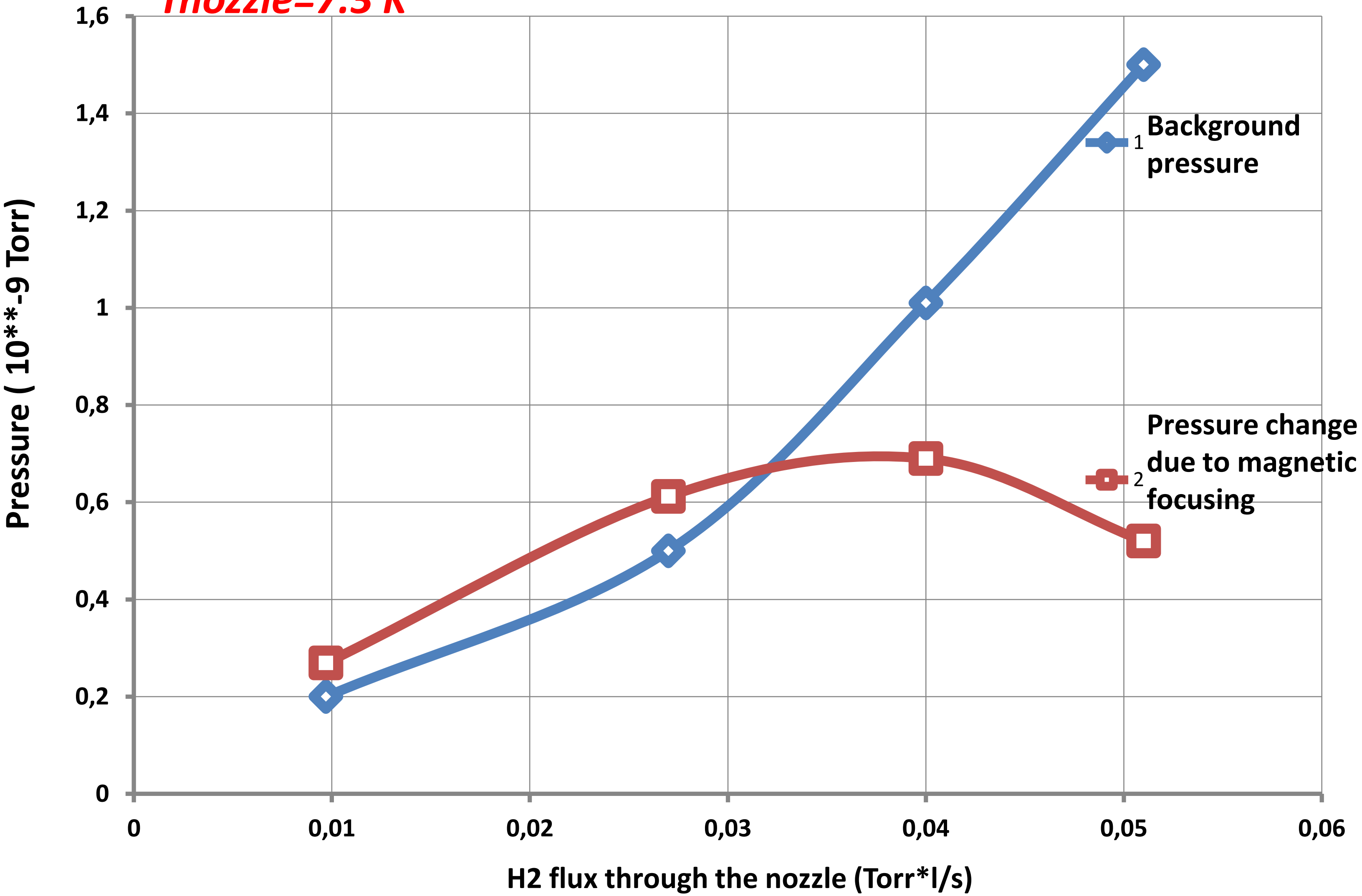


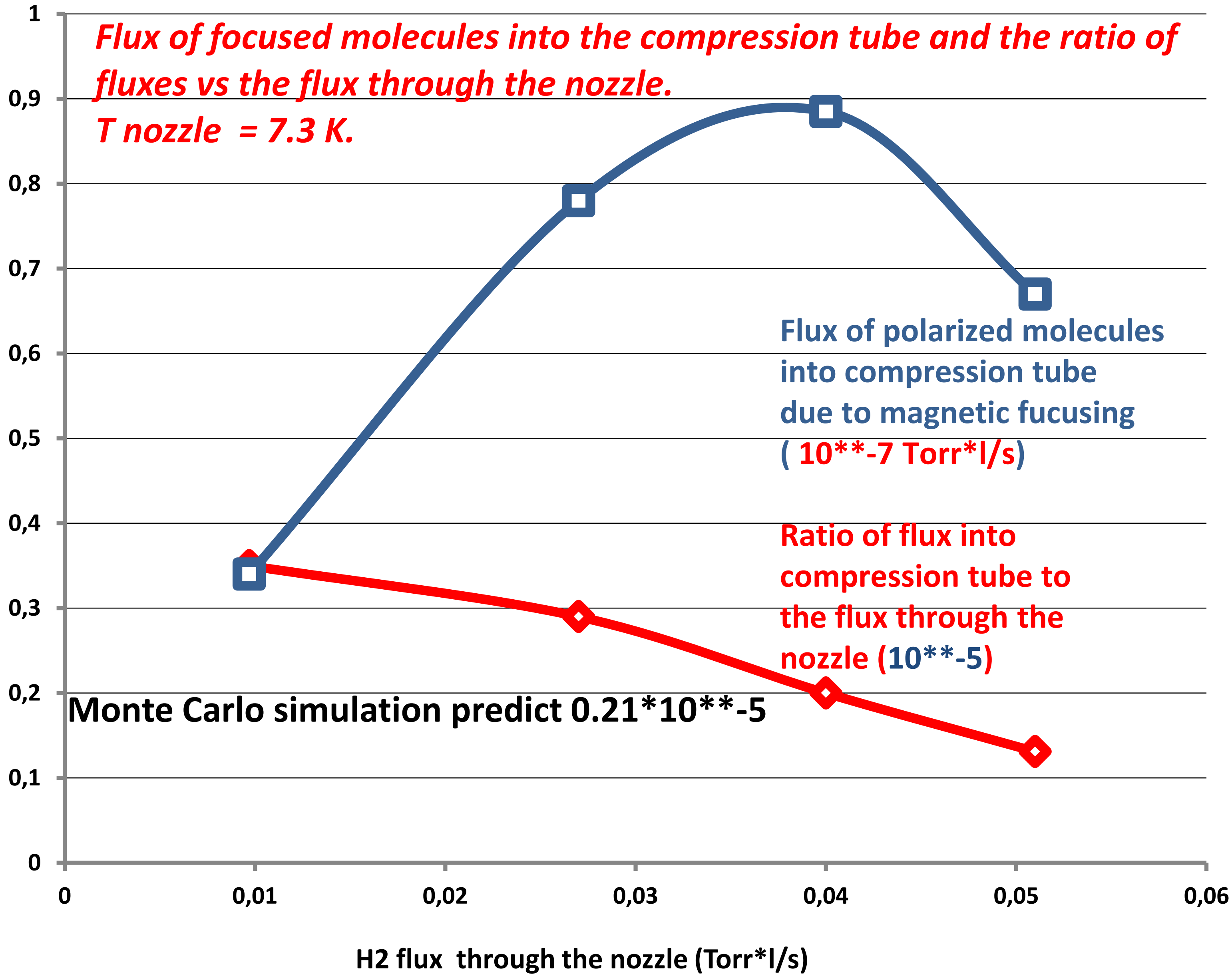
NIM A. 2017. V. 868. P. 15-18. doi 10.1016/j.nima.2017.06.038

Temperature dependence of focusing beam



Background pressure in compression tube and pressure change due to magnetic field vs the flux through the nozzle Tnozzle=7.3 K





Flux of focused molecules into the compression tube and the ratio of fluxes vs the flux through the nozzle.
T nozzle = 7.3 K.
Flux of polarized molecules into compression tube due to magnetic fucusing (10**-7 Torr*l/s)
Ratio of flux into compression tube to the flux through the nozzle (10**-5)
Monte Carlo simulation predict 0.21*10**-5
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
0,01
0,02
0,03
0,04
0,05
0,06
H2 flux through the nozzle (Torr*l/s)

PROBLEM

Why the intensity of the focused beam is going down with the increasing of the flux through the nozzle while the background signal is increasing ?

- ***Attenuation of the beam by the residual gas***
- **Directivity of the flow from the nozzle is falling down with increasing of flux**
- ***Probably at higher pressure in the nozzle clusters of molecules are produced which not focused by the magnetic field***

ATTENUATION OF THE BEAM BY RESIDUAL GAS

The pumping speed is about 18000 l/s. S ~ (950 cm^2)

Flux of molecules $4\cdot10^{-2}$ Torr·l/s.

Pressure $P=2\cdot10^{-6}$ Torr.

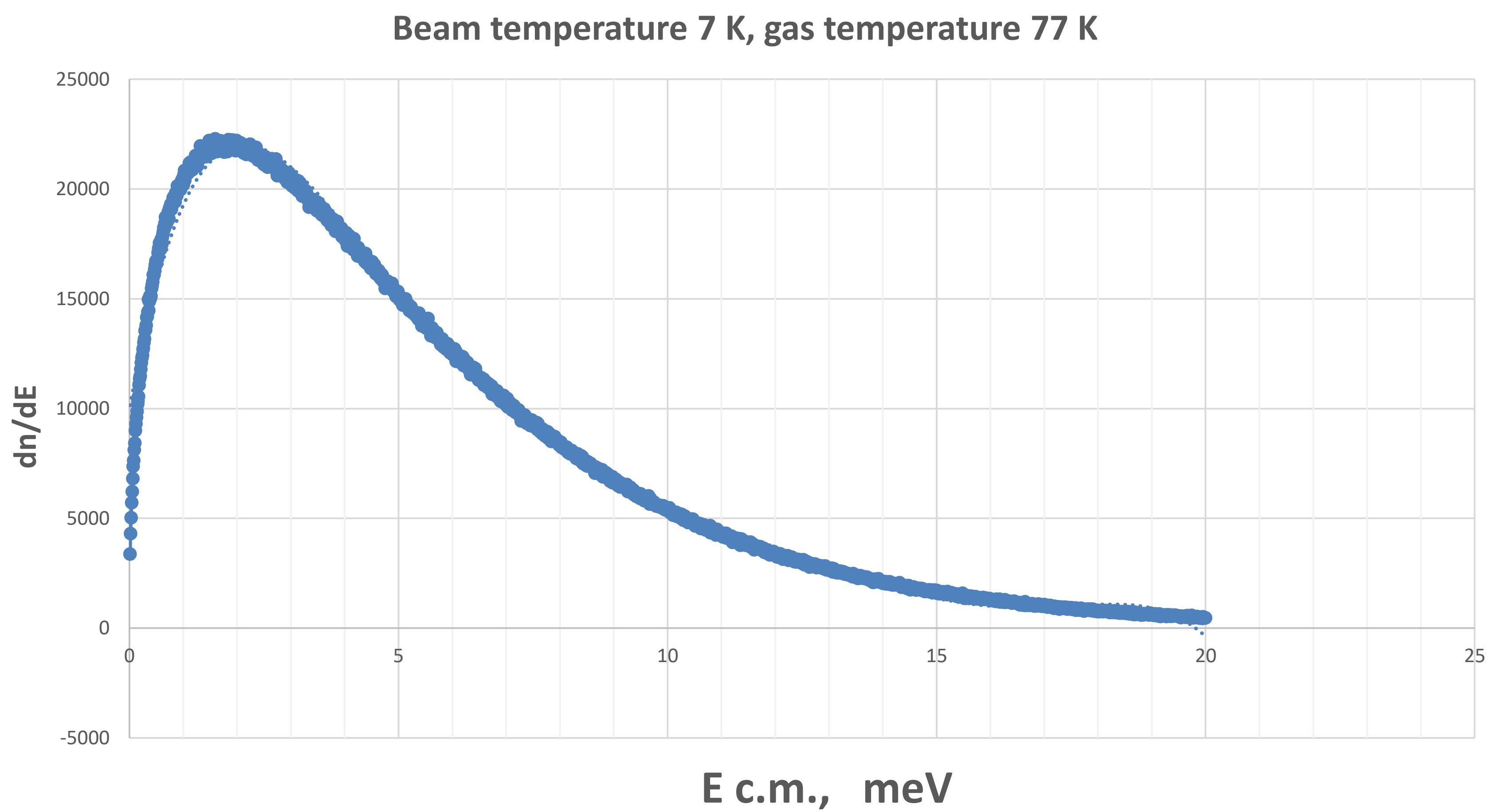
Density $2.5\cdot10^{11}$ mol/cm^3 (T~ 70K).

Thickness of the residual gas is *$n\cdot L = 0.09\cdot10^{14}$ mol/cm^2*.

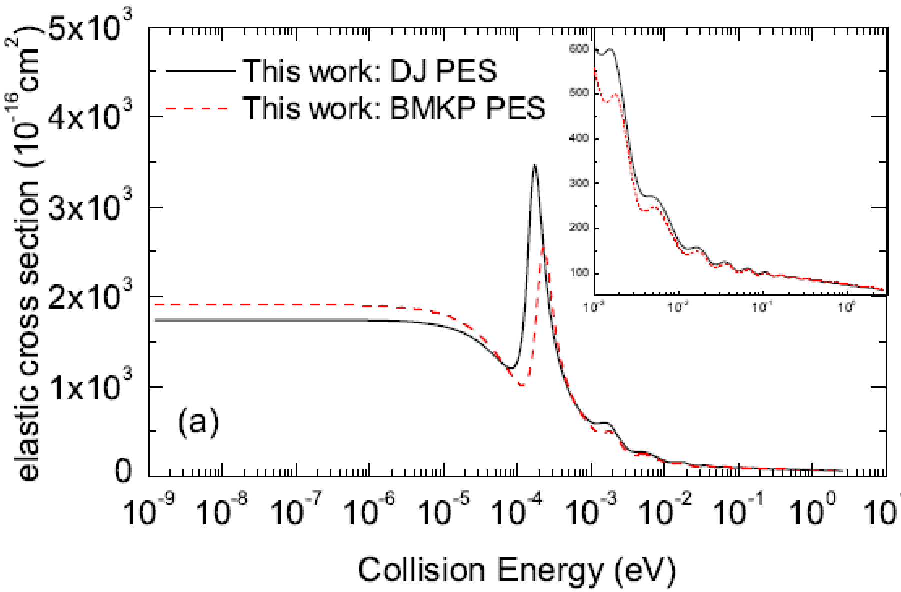
The cross section of H_2-H_2 scattering is *$\sigma = 3\cdot10^{-14}$ cm^2*

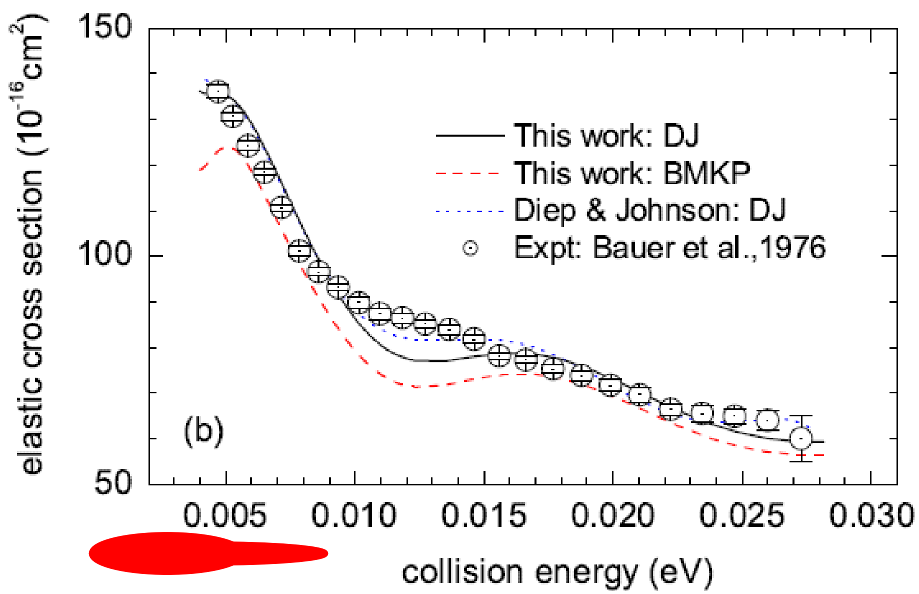
$$I=I_0\cdot exp\text{-}n\cdot L\cdot\sigma= I_0\cdot exp\text{-}0.27= I_0\cdot0.76$$

Collision energy distribution



Elastic cross section as a function of collision energy.





arXiv:physics/0607168v1 [physics.atom-ph] 18 Jul 2006

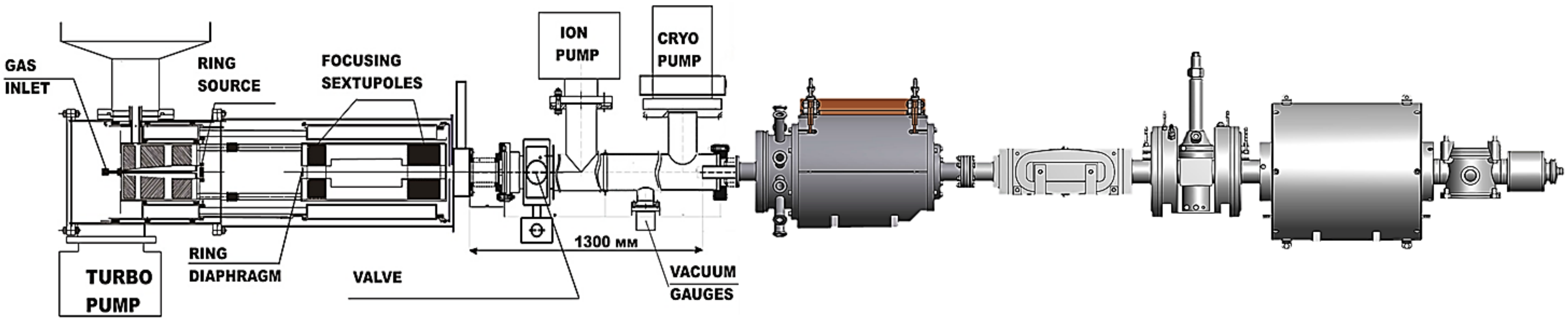
Future prospect

- Measurement of the nuclear polarization of molecules using Lamb-shift polarimeter
- Understanding the process of the beam attenuation by the residual gas and the reflection of molecules from the cold surface
- Working on the directivity of the molecular beam
- Design the prototype of a new source

MOLECULAR SOURCE WITH LAMB-SHIFT POLARIMETER

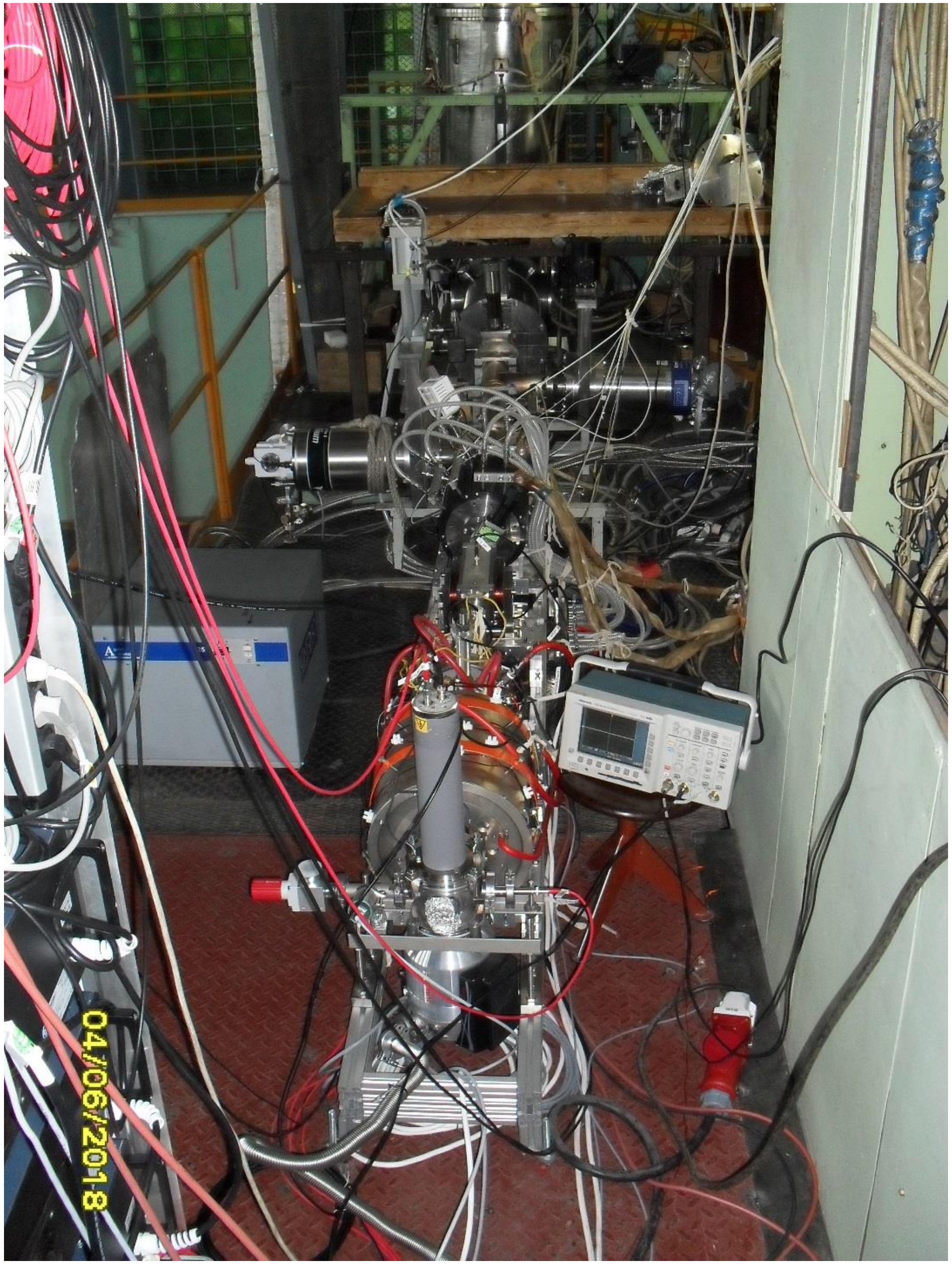
POLARIZED MOLECULAR SOURCE

LAMB-SHIFT POLARIMETER



[Production and Storage of Polarized H2, D2, and HD Molecules]

Presented by **Dr. Ralf ENGELS** on **10 Sep 2018** at **15:30**



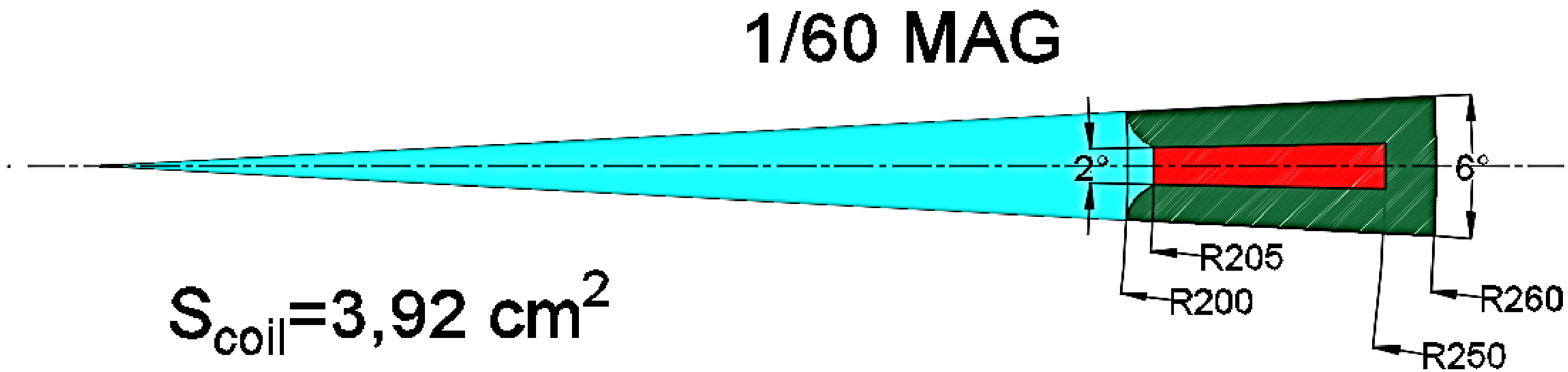
Turning of the polarimeter

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 CMBS
- This investigation has been done under the joint RSF-DFG grants № 16-42-01009 and № BU 2227/1-1

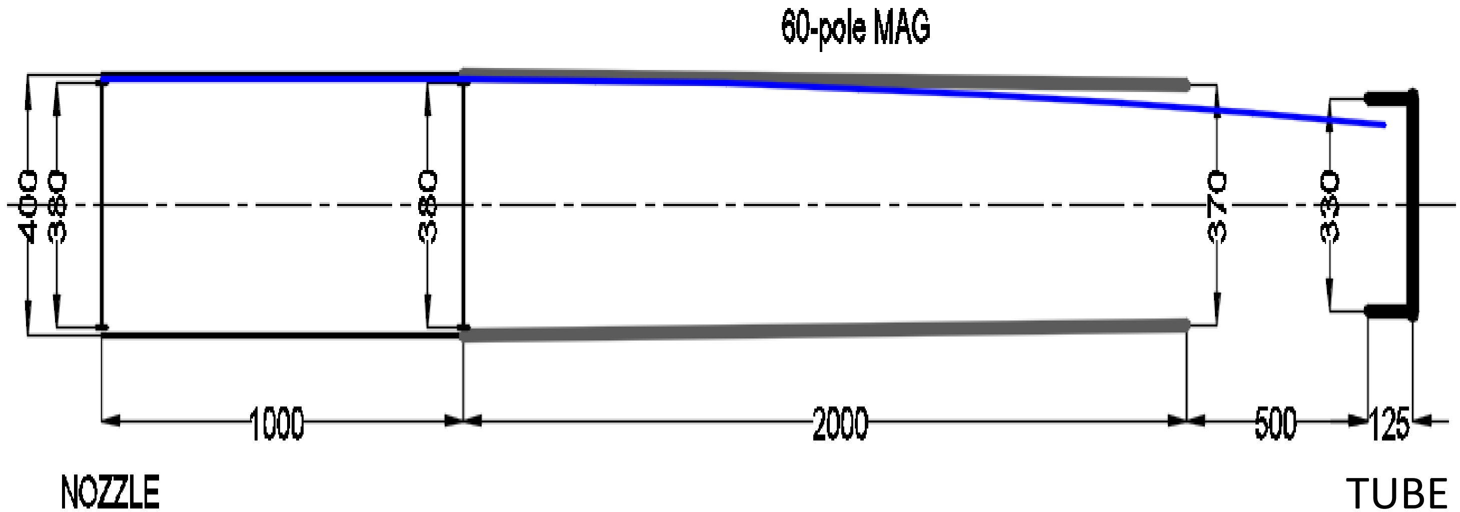
A team working on polarized molecular source

Geometry of the proposed 60 pole magnet



S_{coil}=3,92 cm^2

* dimensions are in (mm)



Possible setup of future polarized hydrogen molecules source