Formation of atomic hydrogen beam and intensity limitations of atomic beam type polarized ion sources and gaseous targets

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Content:

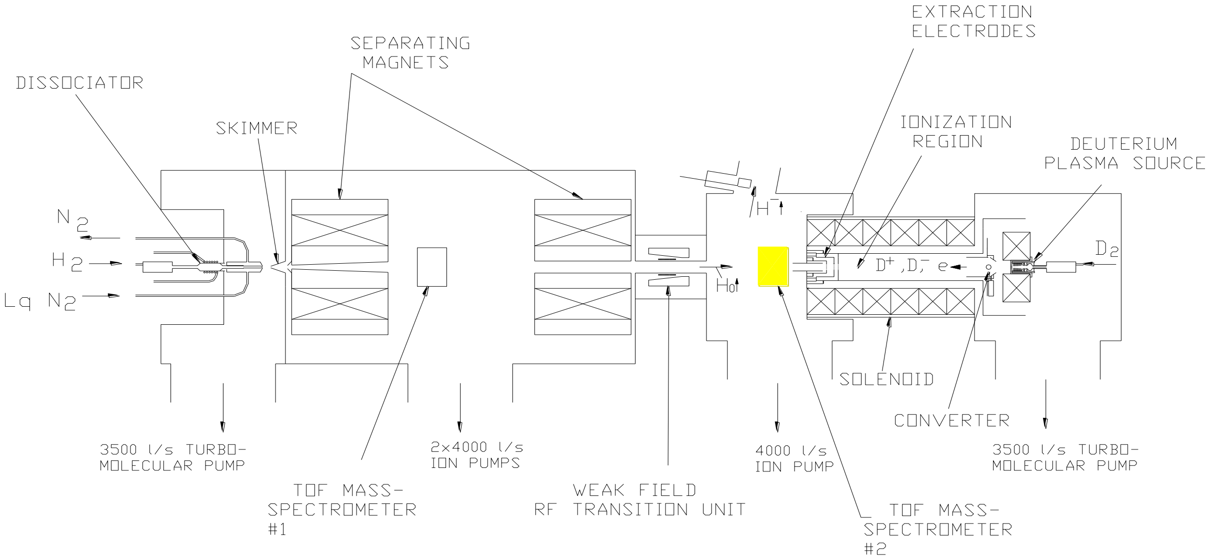
1. Intensity limitation of atomic hydrogen beams
2. Formation of atomic/molecular beams
3. Measurements of radial size of atomic hydrogen beam source at IKP, Juelich
4. Summary

Study of polarized pulsed atomic hydrogen beam at INR RAS

H- current - 4mA

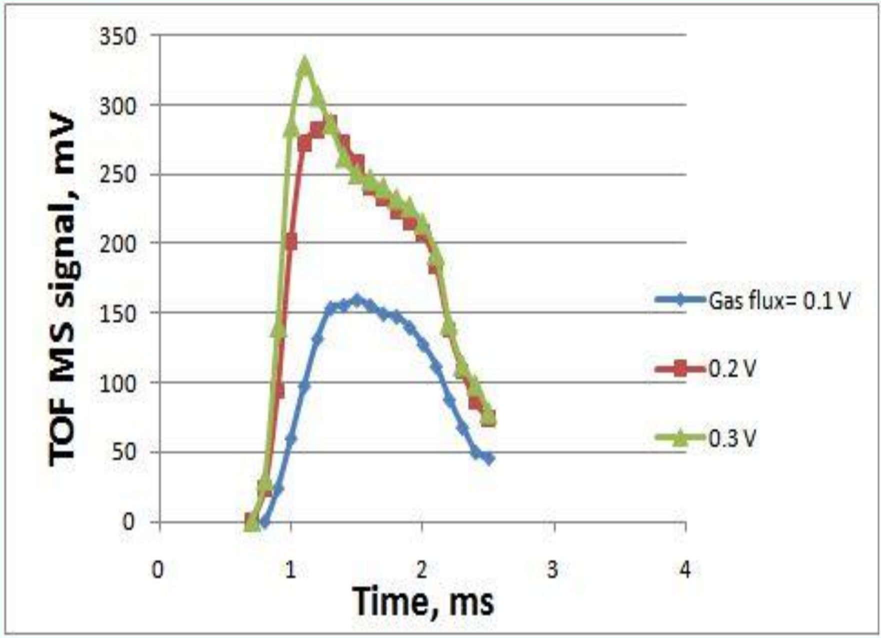
Polarization – 90%

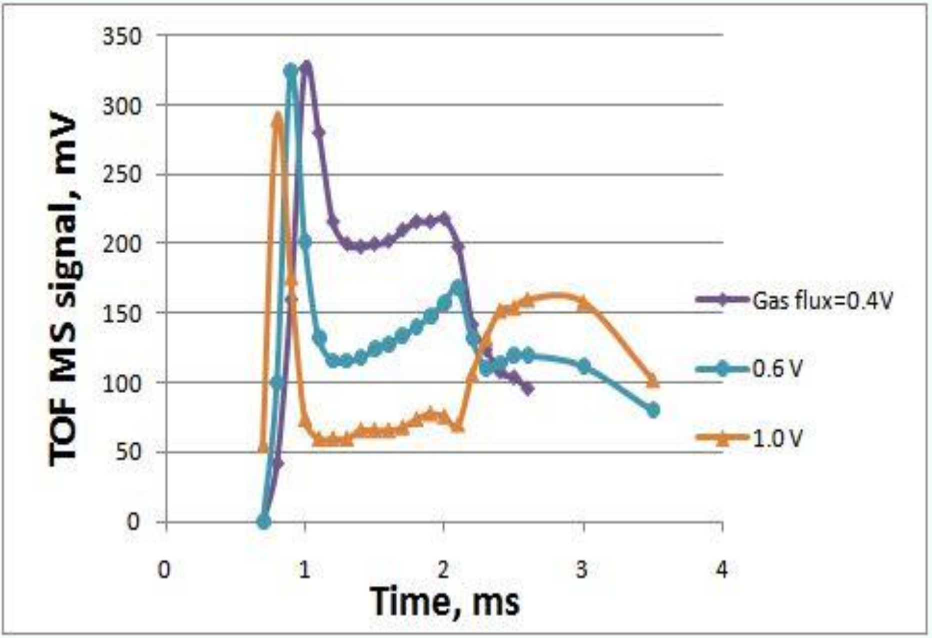
Pulsed operation,
200 μs, 10 Hz

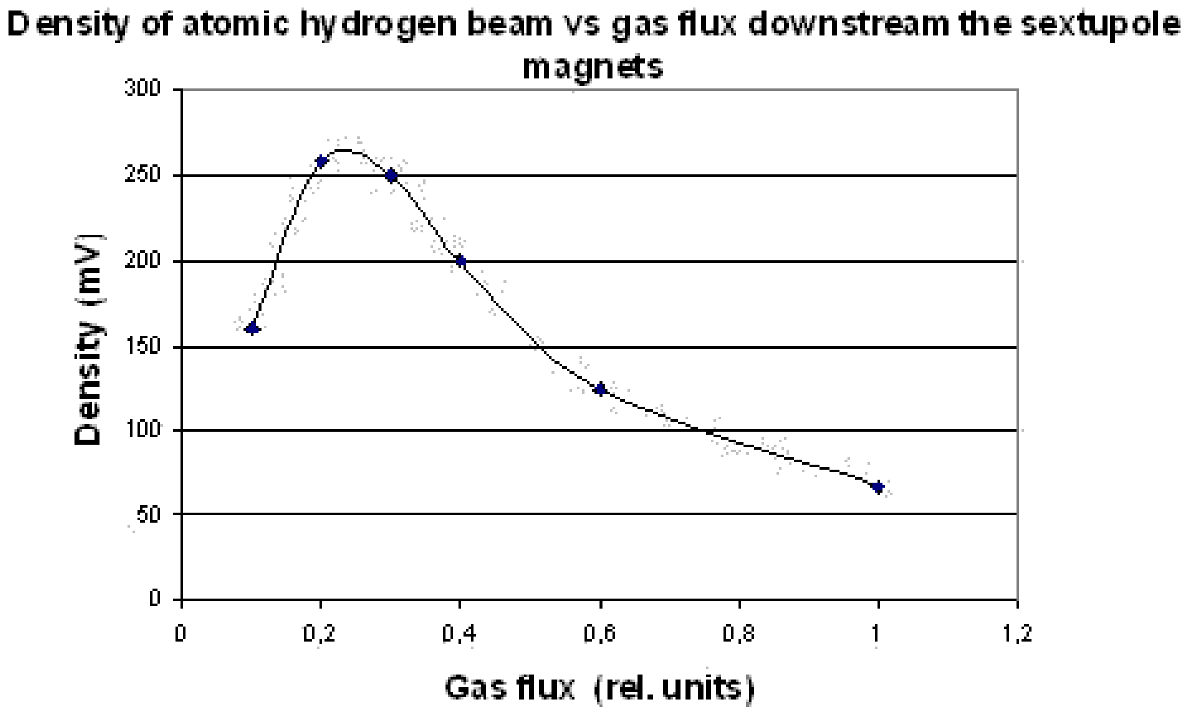


Schematic layout of the apparatus for
study of pulsed polarized atomic hydrogen beam

Pulsed polarized atomic hydrogen beam density measurements (INR source)





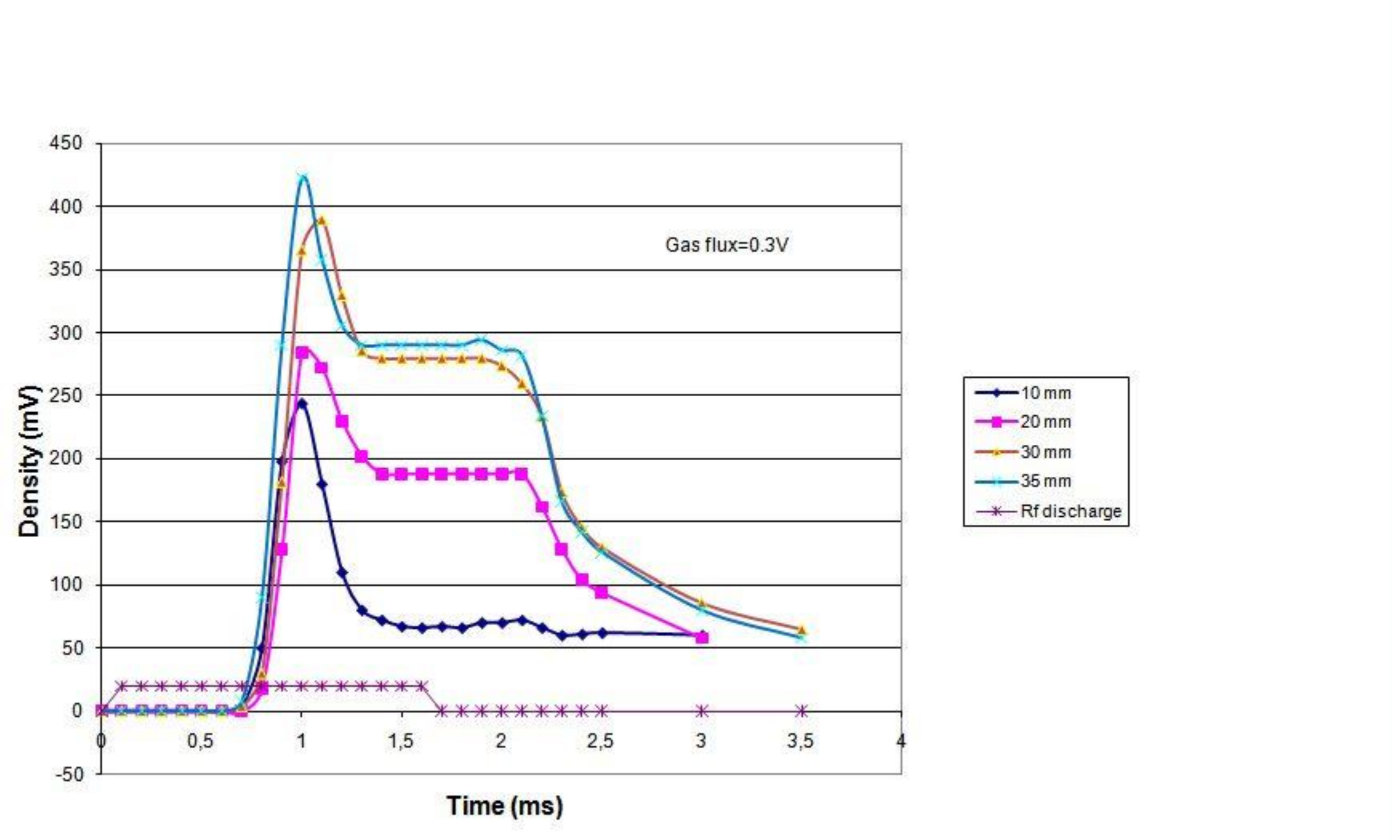

Density of atomic hydrogen beam vs gas flux downstream the sextupole magnets
Density (mV)
300
250
200
150
100
50
0
0
0,2
0,4
0,6
0,8
1
1,2
Gas flux (rel. units)

What is the reason for the pulsed atomic hydrogen beam intensity limitation?

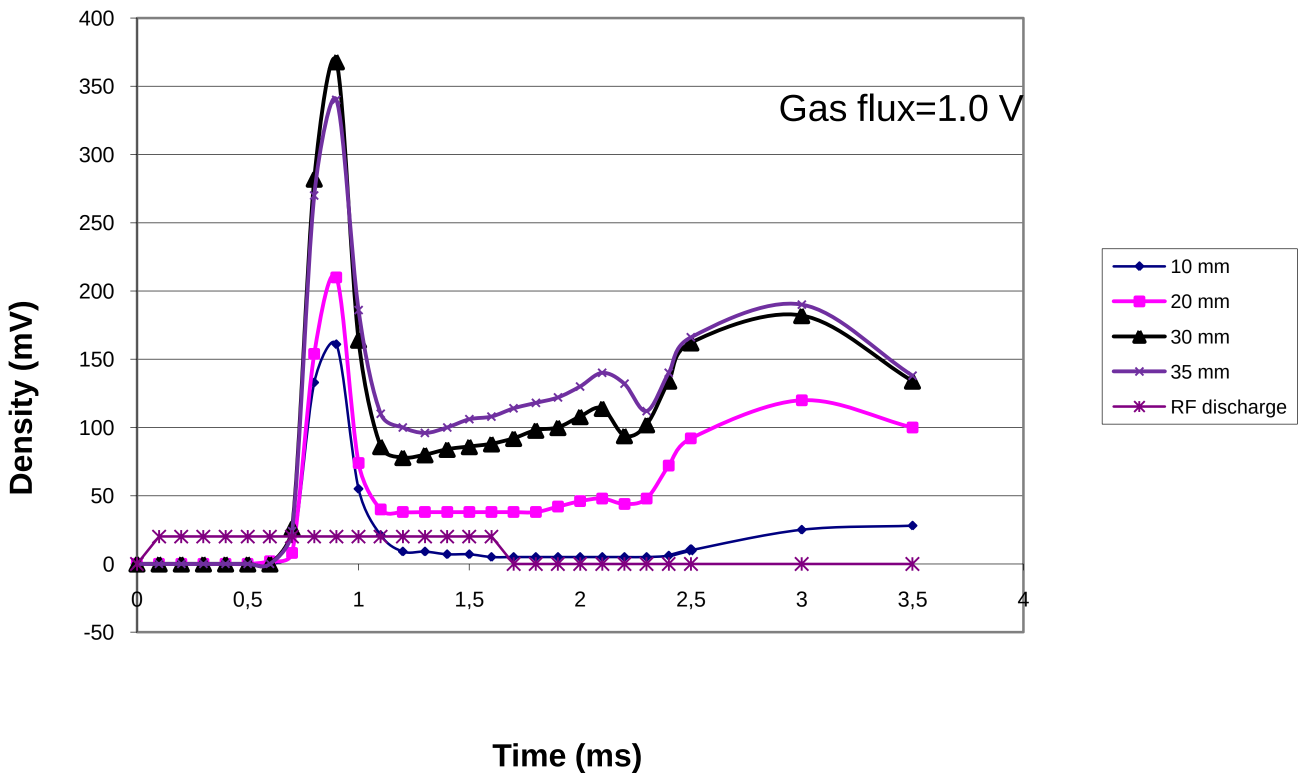
Parameters of velocity distribution change with change of gas flux:

- With increase of gas flux recombination increases
- This can be partially overcome by increase of RF discharge power
- But increase of RF power leads to velocities increase → focusing of faster atoms changes

But we can fix parameters of the RF discharge and change only distance between the skimmer and the dissociator nozzle: strong attenuation of atomic hydrogen beam takes place at small distances between the nozzle and the skimmer

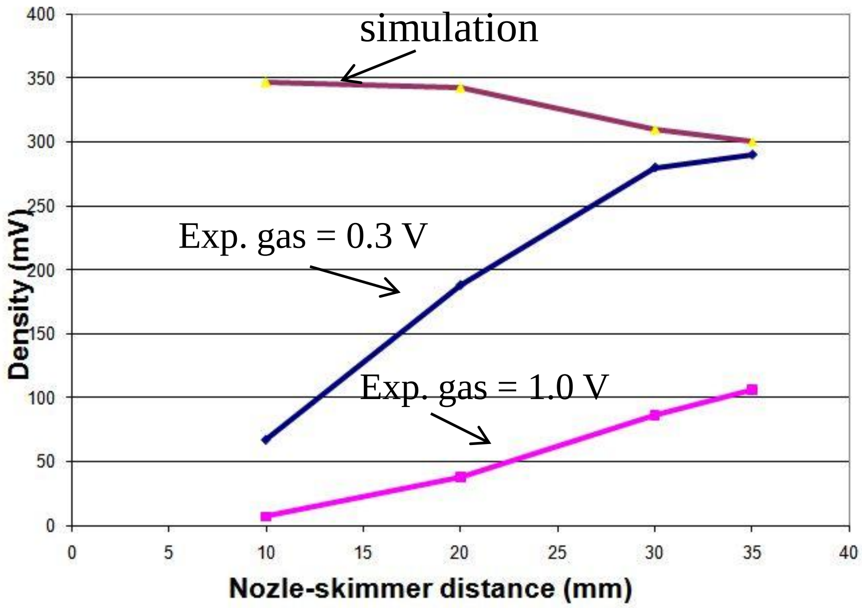


Atomic hydrogen beam dynamic for different distance between skimmer and dissociator nozzle (for big gas flux)

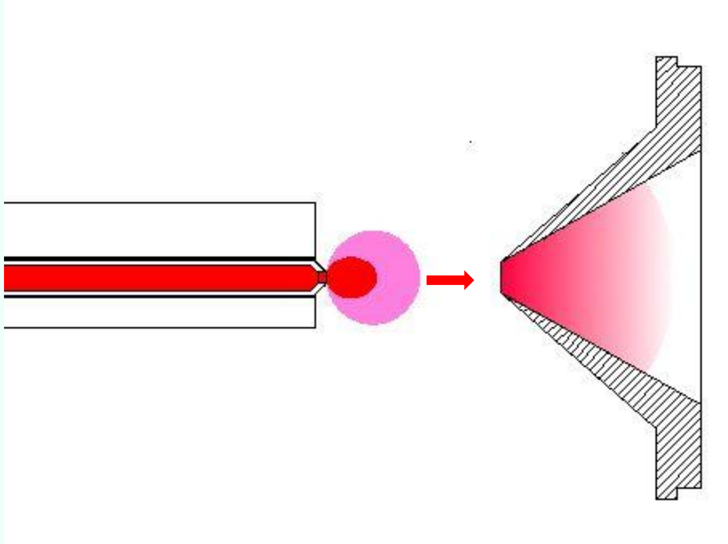


Density of polarized atomic hydrogen beam (at middle of a pulse)
vs
nozzle-skimmer distance

- Density of pulsed atomic hydrogen beam decreases with decrease of the nozzle-skimmer distance while simulation (which does not take into account scattering of atoms) forecasts increase of density



Possible explanation of the observed effects (A. Belov –PSTP2007):



- Hydrogen gas “cloud” is formed inside the skimmer due to restricted skimmer conductance

- Atomic hydrogen beam is attenuated passing through the “cloud” due to scattering

- The “cloud” should produce secondary beam with size larger then the skimmer diameter

Formation of atomic/molecular beams

Effusion: $Kn \geq 1$ (mfp ≥ orifice diameter)

- Cosine angle distribution
- Forward intensity:

$$I_0 = n_0\, v\, A/4\pi \quad (sr^{-1}s^{-1})$$

n_0 is the density of particles in the source

v is the average velocity $v = (8kT_0/\pi m)^{1/2}$

A is the orifice area

- Maximum intensity for effusive sources (Kn~1)

  $I_{0max} \sim 10^{18}$ s^{-1} ster^{-1}

  ($T=80$ K, $d_n = 2$ mm, $n_{0max} \sim 10^{15}$ cm^{-3})

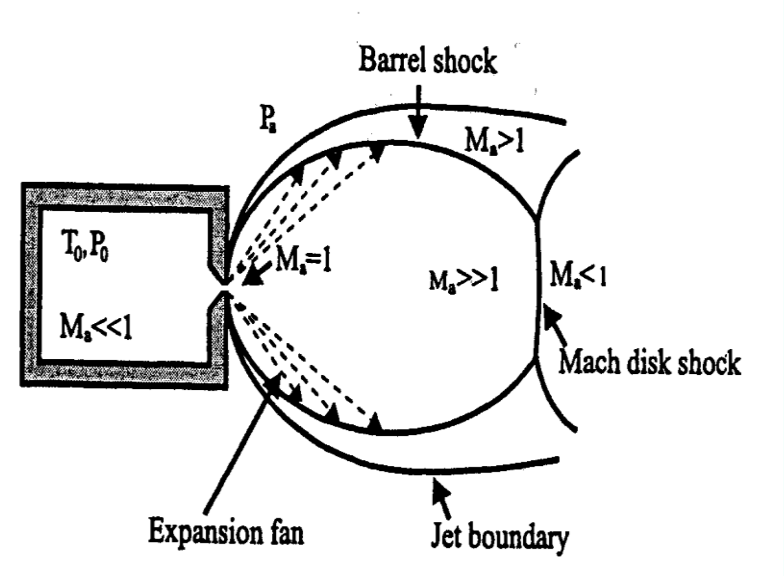
- For effusive sources:

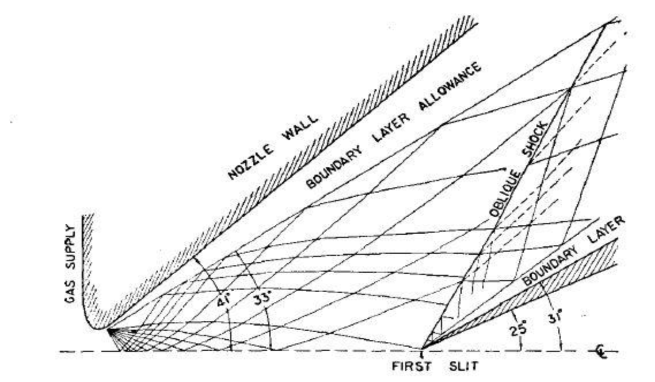
  source diameter = dissociator orifice diameter

Supersonic nozzle

- Use of supersonic nozzle for production of molecular beam has been proposed by
  A. Kantrowitz and J.Grey in 1951

  Kn <<1 (mfp << nozzle diameter)
- Gaseous jet expansion through a sonic nozzle to a gas with ambient pressure P_a
- Efficientcooling during the jet expansion
- Complex phenomena including shock formation





Supersonic nozzle in ABS

- **Hydrogen flux ~ 1 mbar l s^{-1} (5 10^{19} s^{-1}), Kn ~ 0,02**
- **Density in an expanding hydrogen jet drops with distance from a nozzle as:**

$$n(z) \cong n_0/\ (1+z^2/r_n^{\ 2})$$

Density decreases two orders of magnitude at distance $z/r_n \cong 10$. After this point collisions become rare (freezing surface) and jet becomes source of molecular beam

- **For supersonic nozzle source:**

Source diameter is determined by freezing surface geometry

- **D. K. Toporkov (2004) suggested that freezing surface effective diameter can be larger then a skimmer diameter (screening effect)**

- **Intra jet scattering does not stop abruptly. It changes the source size too.**

- **For condition of ABS normal density shock (Mach disk shock) moves far away from a nozzle**

  $Z_M/d \sim \surd(P_0/P_a)$
  for $P_0 \sim 1$ mbar, $P_a \sim 10^{-4}$ mbar
  $Z_M/d \sim 10^2$

- **DMCS does not show another density shocks formation in ABS**

Measurements of radial size of atomic hydrogen beam

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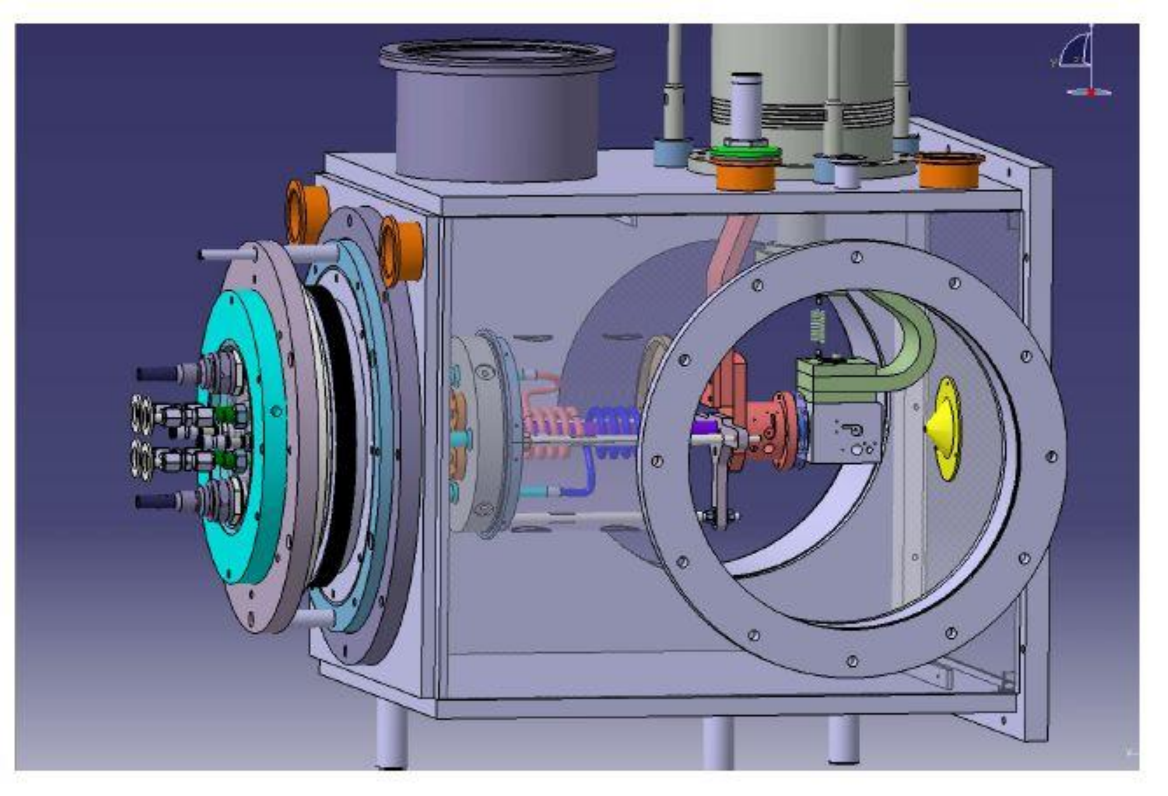
COSY – Juelich pulsed RF discharge dissociator

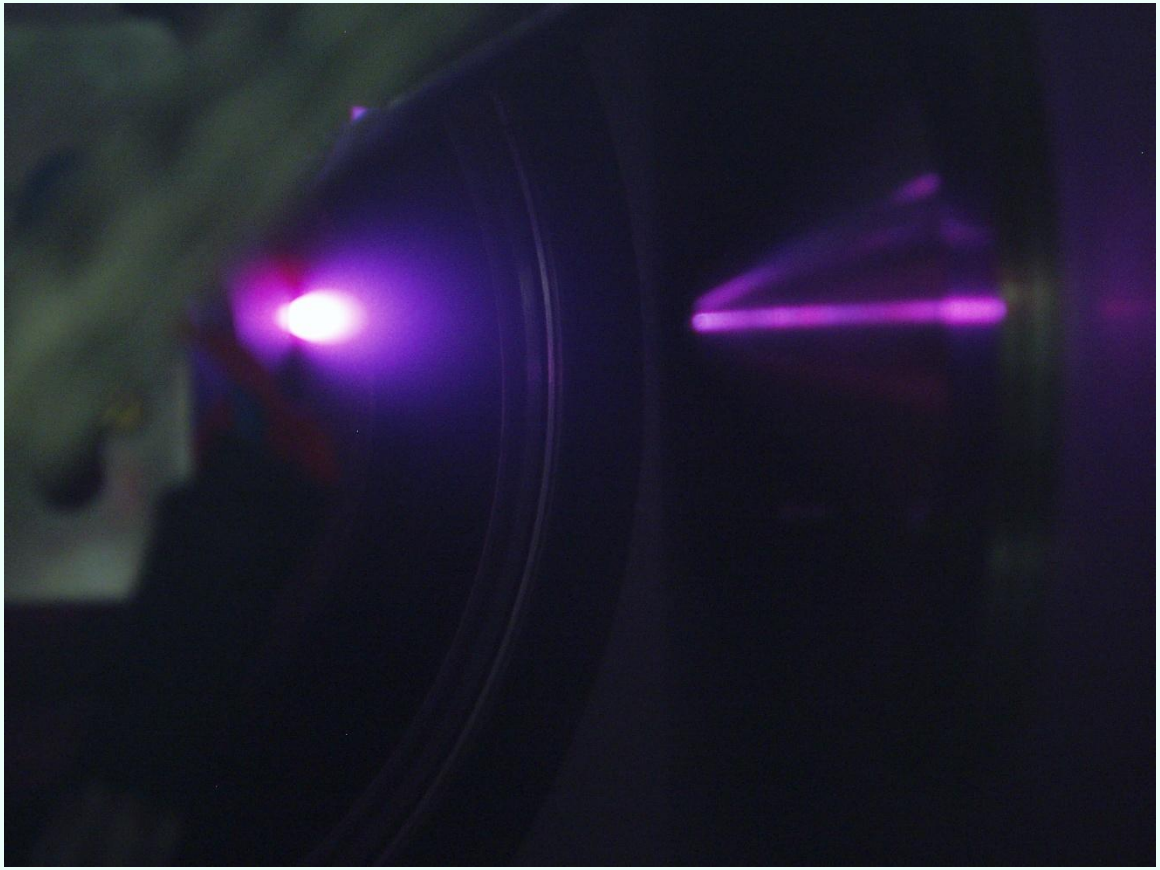
RF pulse duration
~20 ms

Rep. rate – 1 Hz



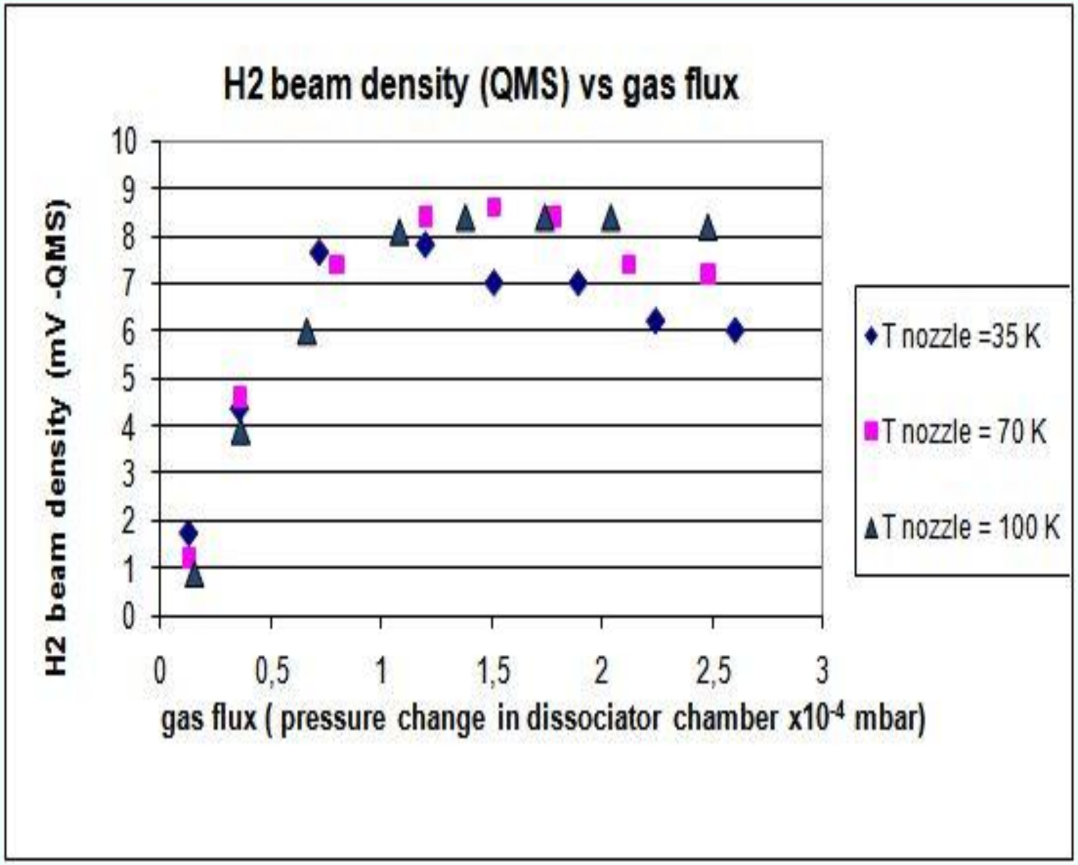
Nozzle radius =1.25 mm, Skimmer radius =3 mm,
nozzle-skimmer distance =35 mm

Photo picture of nozzle-skimmer region of COSY test-bench dissociator

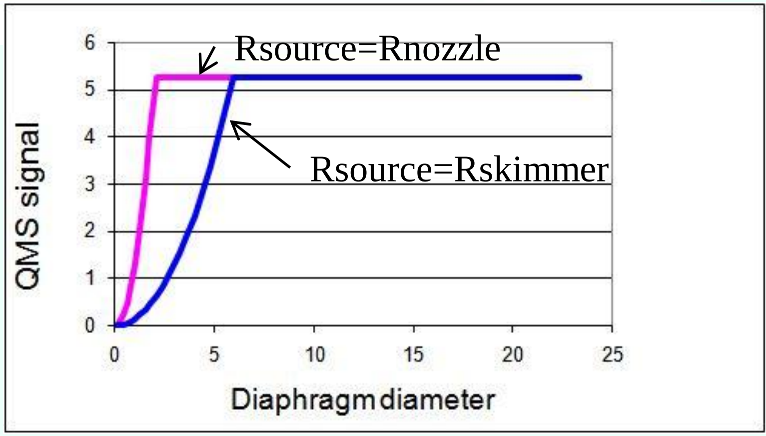


- Molecular hydrogen beam density is restricted in spite of pulsed mode of gas supply

- H_2 beam density saturation takes place at gas flux (pressure change in dissociator vacuum chamber) = (1-1.5) 10^{-4} mbar

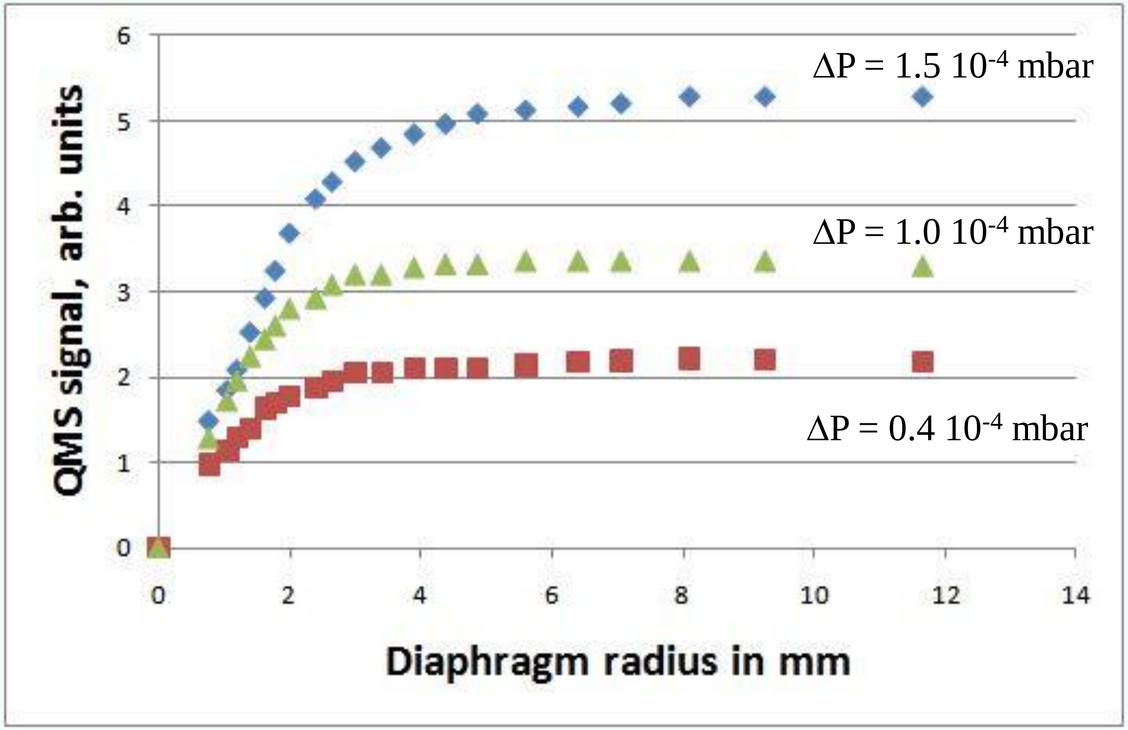


Schematic of apparatus for hydrogen beam source size measurements



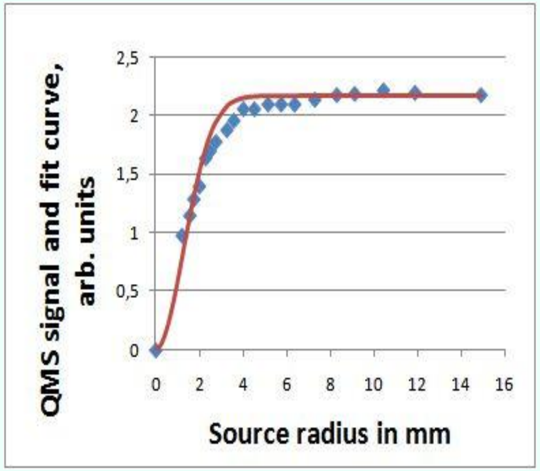
Results of measurements of atomic hydrogen source size for different molecular hydrogen gas flux with diaphragm method

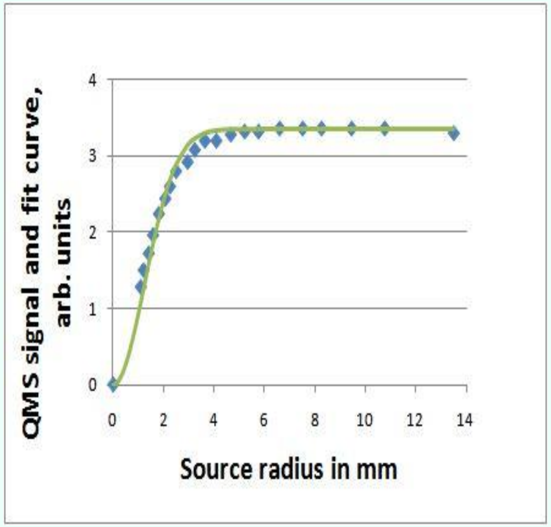
Nozzle radius =1.25 mm, Skimmer radius =3 mm, H atoms

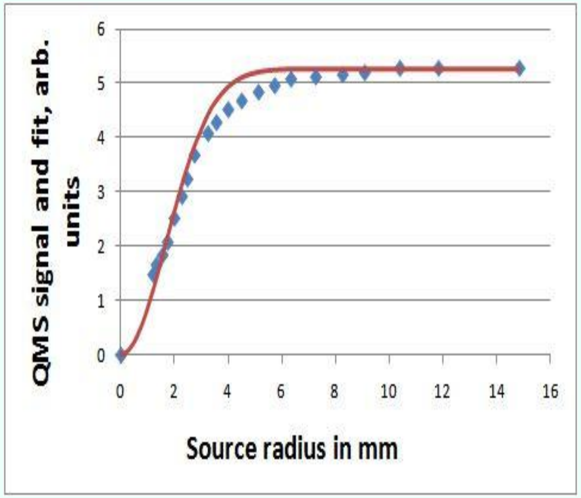


Fit of data by Gaussian distribution

Nozzle radius =1.25 mm, Skimmer radius =3 mm, H atoms







$\Delta P = 0.4\ 10^{-4}$ mbar,
R=1,74 mm

$\Delta P = 1.0\ 10^{-4}$ mbar,
R=1,78 mm

$\Delta P = 1.5\ 10^{-4}$ mbar,
R=2,4 mm

Nozzle radius =1.25 mm,
Skimmer radius =3 mm,
H atoms

Comparison of

Fit of data by one gaussian distribution:

$F = A_1\ (1\text{-}\exp(-r^2/R_1^2))$

R_1 = 2.4 mm

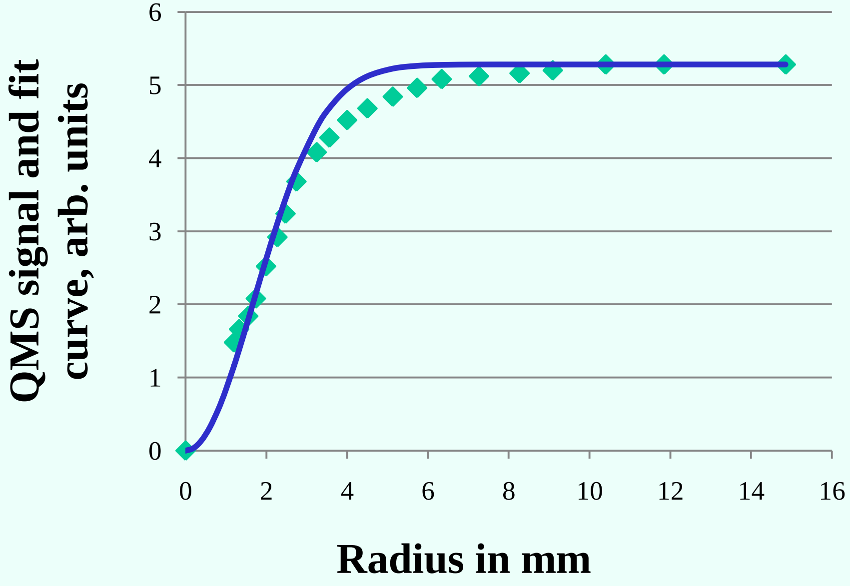
and

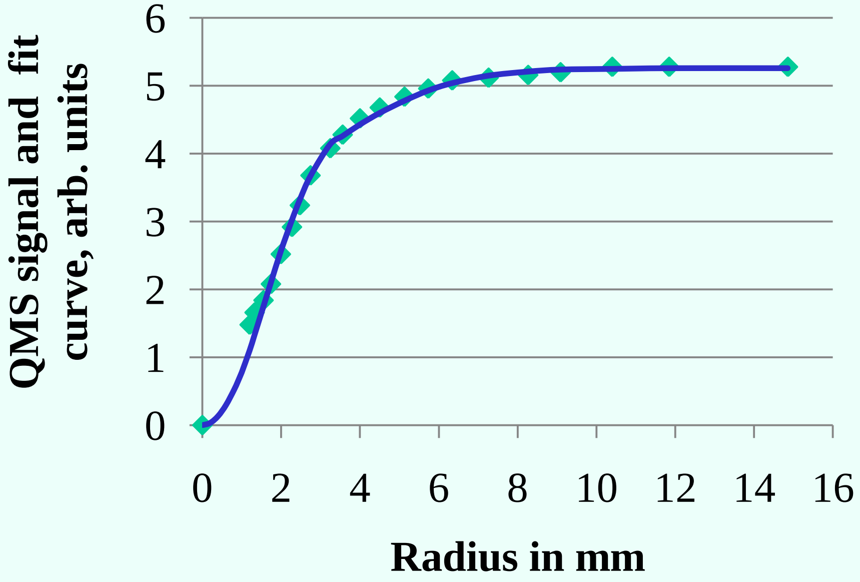
Fit of data by two gaussian distributions:

$F = A_1\ (1\text{-}\exp(-r^2/R_1^2)) +$
$+A_2\ (1\text{-}\exp(-r^2/R_2^2))$

R1=1,9 mm R2=4,22mm

A_1 =3,6 A_2 =1,94





Nozzle radius =1.25 mm,
Skimmer radius =3 mm,
H atoms

Comparison of

Fit of data by one gaussian distribution:

$F = A_1 (1-\exp(-r^2/R_1^2))$

$R_1 = 2.4$ mm

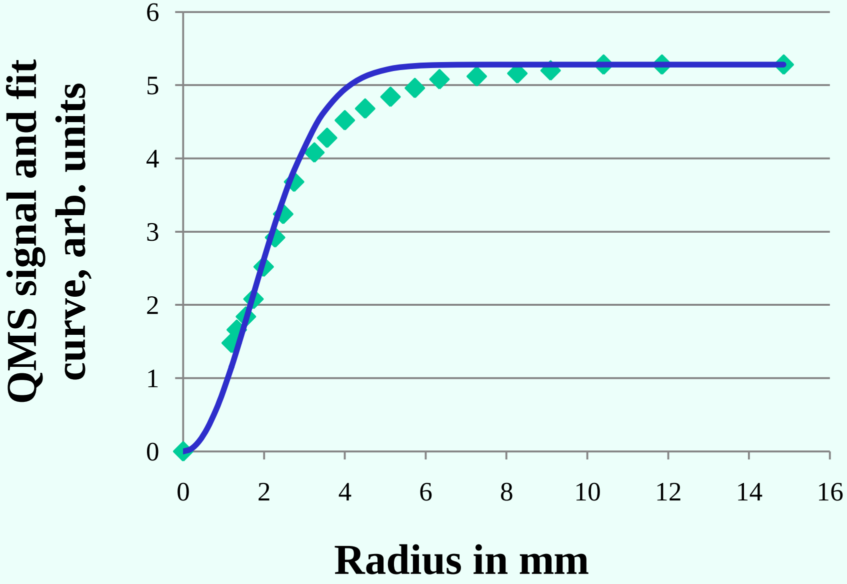
and

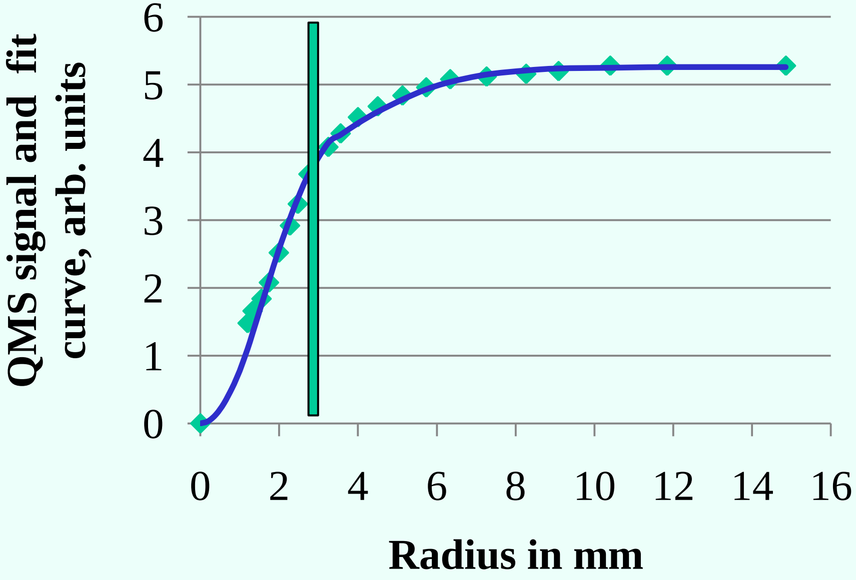
Fit of data by two gaussian distributions:

$F = A_1 (1-\exp(-r^2/R_1^2)) +$
$+A_2 (1-\exp(-r^2/R_2^2))$

R1=1,9 mm R2=4,22mm

$A_1 = 3{,}6$ $A_2 = 1{,}94$



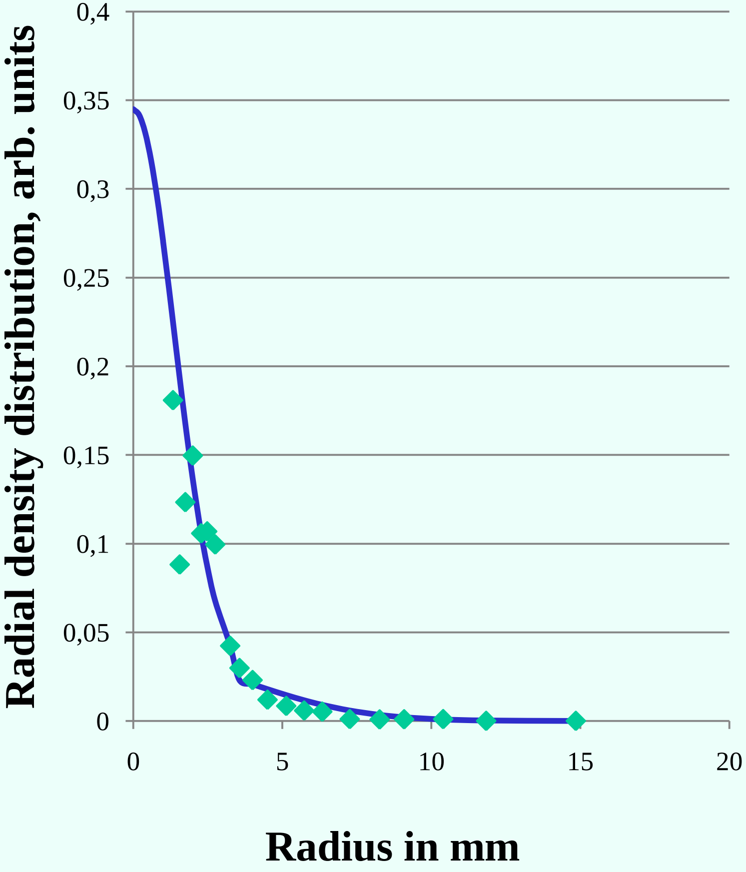


Nozzle radius =1.25 mm, Skimmer radius =3 mm, H atoms

Radial density distribution

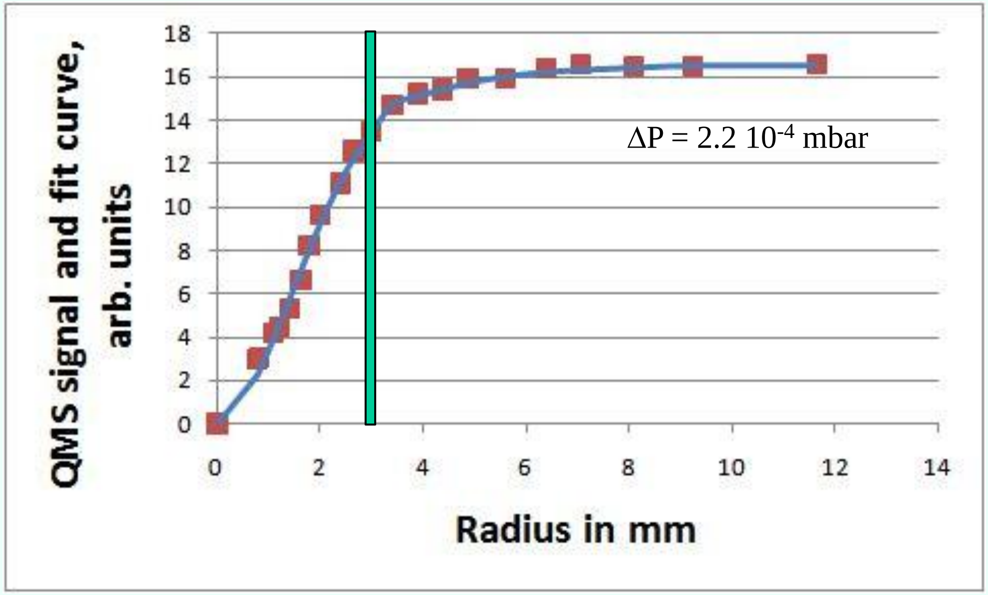
(fit by two gauss curve):

$$n(r) = A_1 \exp(-r^2/R_1^2) +$$
$$+A_2 \exp(-r^2/R_2^2)$$



Results for hydrogen molecular beam

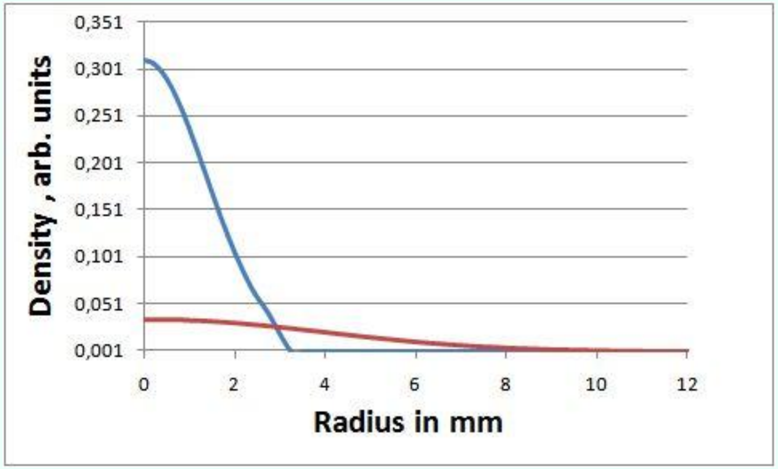
- Nozzle radius =1.25 mm, Skimmer radius =3 mm, H_2 molecules

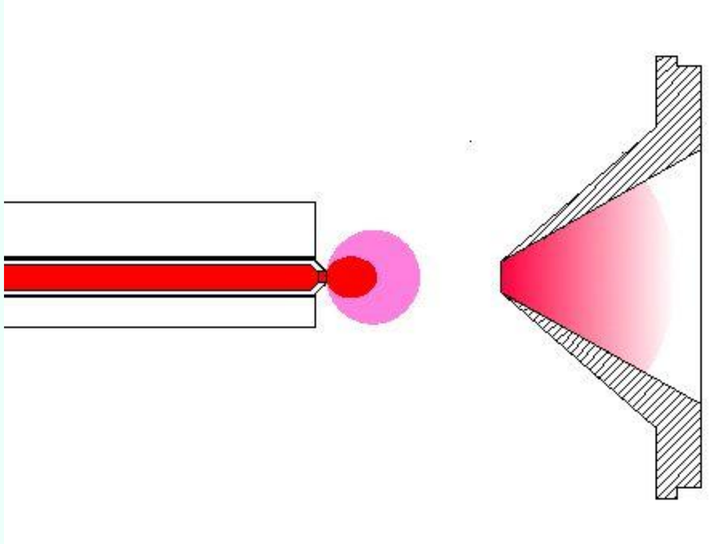


R_1=2.4 mm, R_2 = 4.5 mm

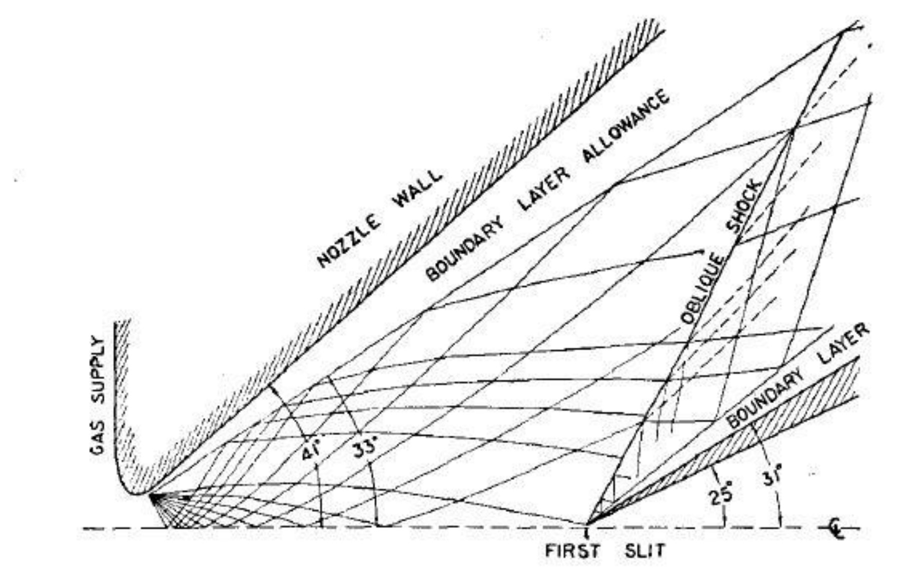
The measurements confirm suggestion concerning attenuation of atomic hydrogen beam from ABS due to scattering on gas cloud inside the skimmer:

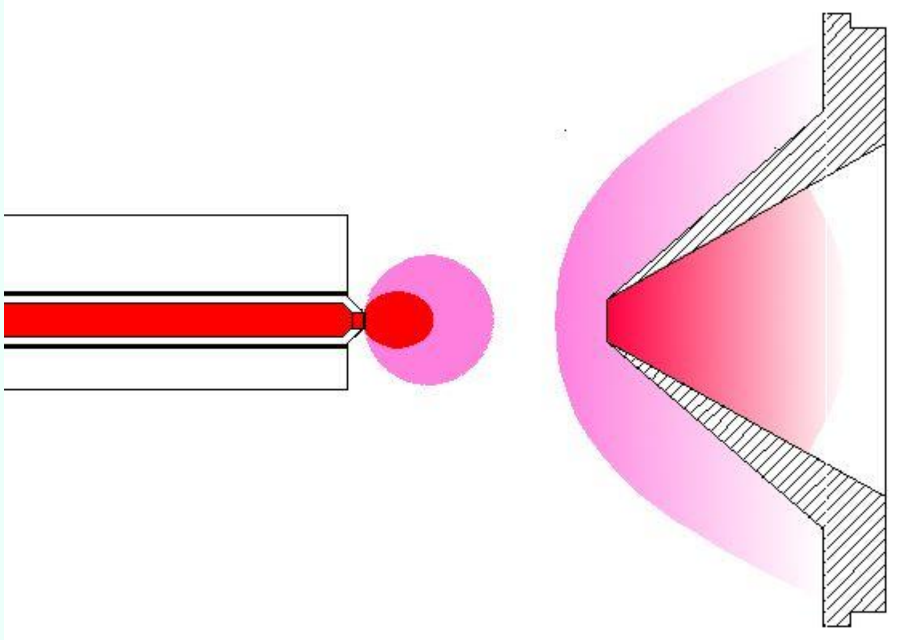
There are two sources of hydrogen atoms, one upstream the skimmer and another downstream the skimmer.





- **Secondary source arises probably due to density shock at the skimmer orifice which is produced by an intense hydrogen jet**





How to avoid the density shock formation?

- Increase nozzle-skimmer distance (for INR source this works well)

  However,
  - sextupole magnet geometry should be optimized for larger distance
  - scattering on residual gas in dissociator chamber will increase.

- Optimize skimmer geometry

  However,
  - It is important to see the effect in simulation. Up to now DMCS does not show formation of density shocks.

Summary

- Characteristic radial size of atomic hydrogen beam source of COSY ABS increases with gas flux from 1.7 mm to 1.9 mm (while nozzle radius was 1.25 mm and skimmer radius – 3 mm).

- Tails in radial distribution of the atomic hydrogen source density with size larger then skimmer radius appear at high gas flux. This is connected probably with formation of density shock around skimmer orifice and gas cloud inside the skimmer. By this way secondary source of hydrogen atoms arises with radial size larger then the skimmer radius.

- Limitation of intensity of a ABS can be connected with scattering of atomic hydrogen beam on a density shock at a skimmer.

- It is important to take into account radial size of atoms source for optimization of ABS apparatus .