Design of Transversal Phase Space Meter for Atomic Hydrogen Beam Source

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Intensity limitations of polarized atomic hydrogen beams

- Intensity of ABS working dc is limited at level of ~10^{17} at/cm^2·sec

  RHIC jet target: I = 1,2·10^{17} at/cm^2·sec

  ANKE jet target: I = 8,2·10^{16} at/cm^2·sec

  Novosibirsk: I = 1·10^{17} at/cm^2·sec

- For ABS working in pulsed mode intensity of 2 ·10^{17} at/cm^2·sec has been obtained (INR RAS polarized ion source)

- No significant progress since implementation of cooling of atomic hydrogen to 35-80 K and use of high-field permanent sextupole magnets (FILTEX target ~20 years ago: I = 8 ·10^{16} at/cm^2·sec)

Many processes can be a reason for restriction of ABS intensity:

- Attenuation of atomic beams by scattering with residual gas molecules
- Intra beam scattering
- Increase of size of atoms source with increase of gas flux
- Recombination of atomic hydrogen
- Emittance grows due to pressure “bumps” (at skimmer location)

This was discussed at PSTP Workshops many times.

Toporkov D. K. (SPIN 2014**):**

Intra beam scattering is main process that is responsible for ABS intensity saturation.

A.Hershcovitch (PRL 63(1989)750) explained observed reduction of focusing factor of a cold (6K) atomic beam by the intra beam scattering .

Intra beam scattering is principal limitation of the AB intensity.

Pulsed ABS

- In pulsed mode of operation attenuation due to scattering with residual gas molecules is practically eliminated .

- High RF power can be used to move out to higher pressure range a hydrogen atoms recombination in an atomic beam source

- Nevertheless, experience gained at INR with pulsed ABS showed that intensity limitation exists for the pulsed ABS as well.

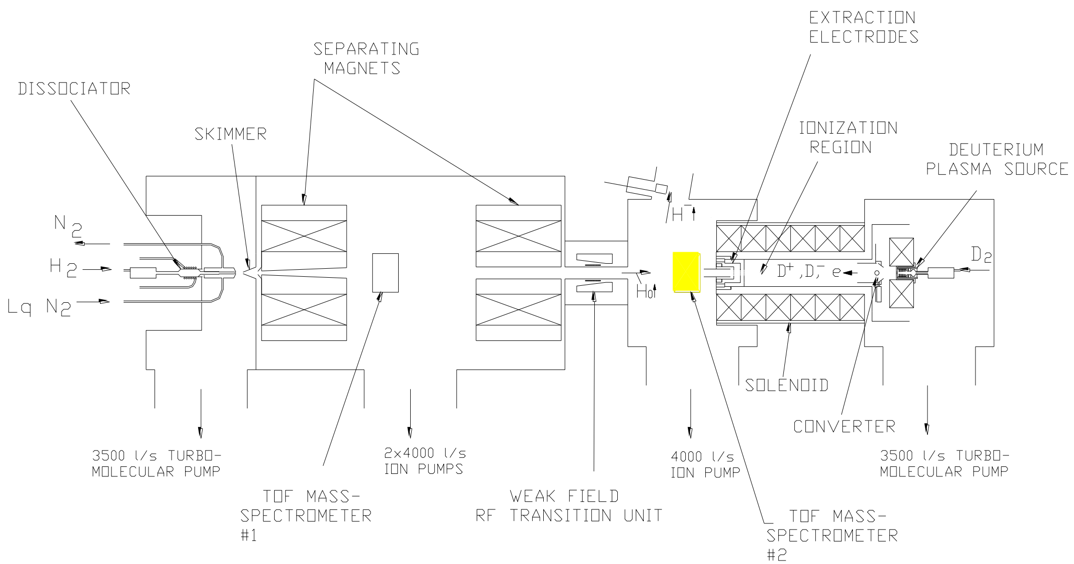
Polarized pulsed atomic hydrogen beam source at INR RAS

Polarized AB intensity – $2 \cdot 10^{17}$ at/sec

H- current - 4mA (H+ -10 mA)

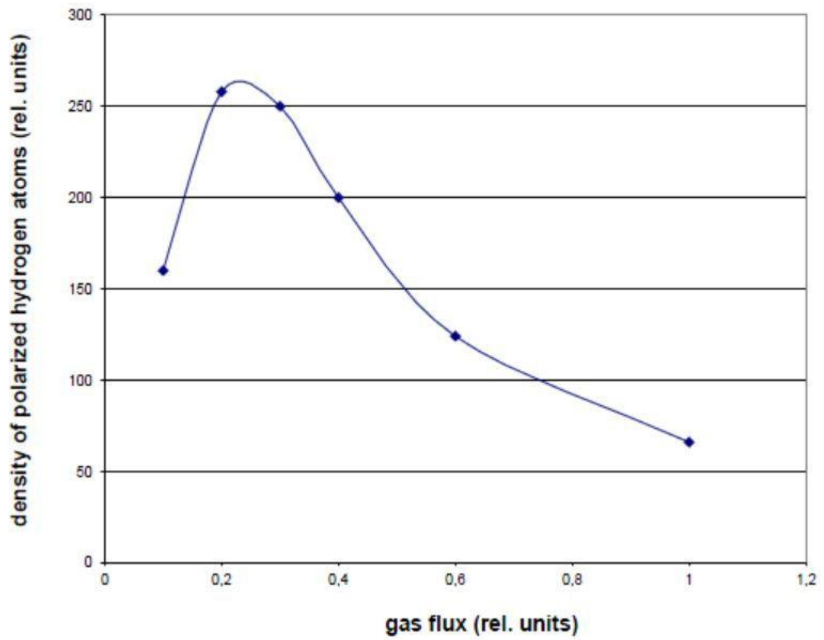
Polarization – 90%

Pulsed operation, 200 μs, 5 Hz



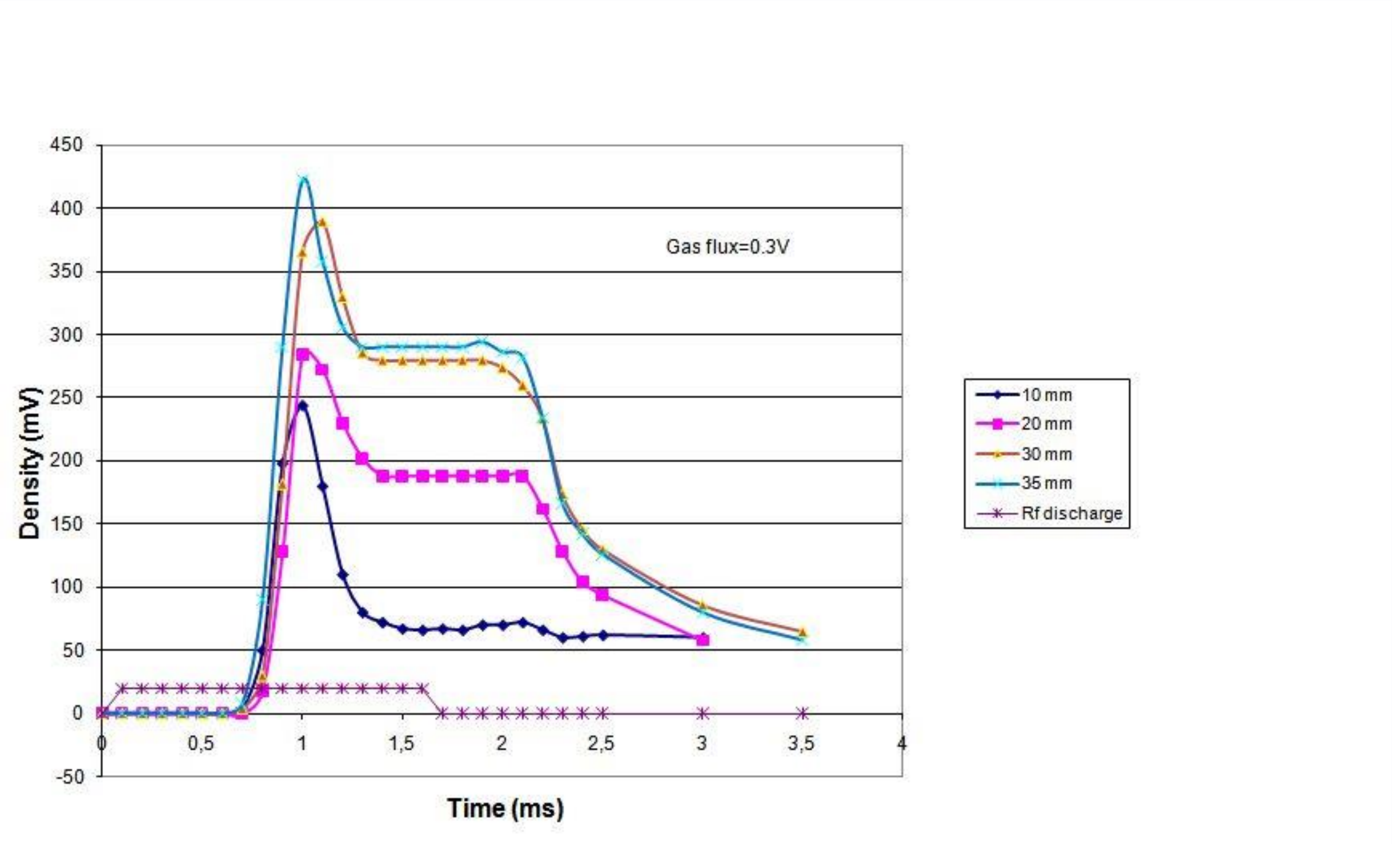
Schematic layout of the apparatus for study of pulsed polarized atomic hydrogen beam

INR RAS pulsed polarized ABS: AB intensity vs. gas flux



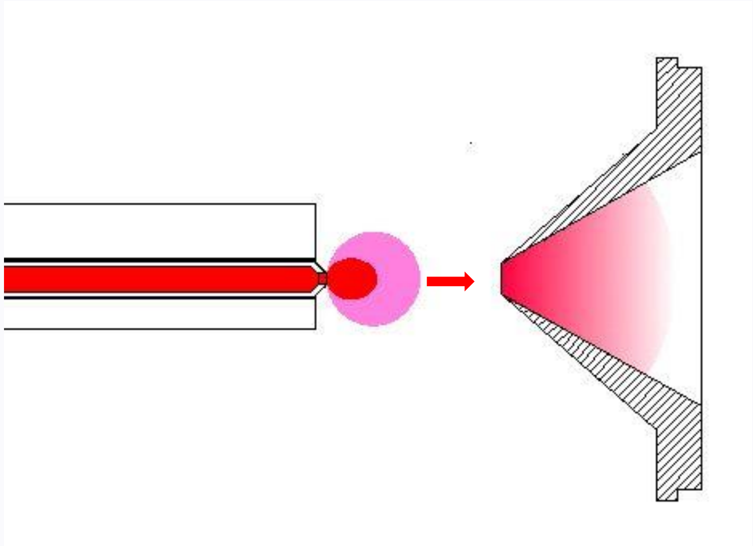
Only distance between the skimmer and the dissociator nozzle is changed:

Strong attenuation of atomic hydrogen beam takes place at small distances between the nozzle and the skimmer



• Possible explanation of the observed effects:

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

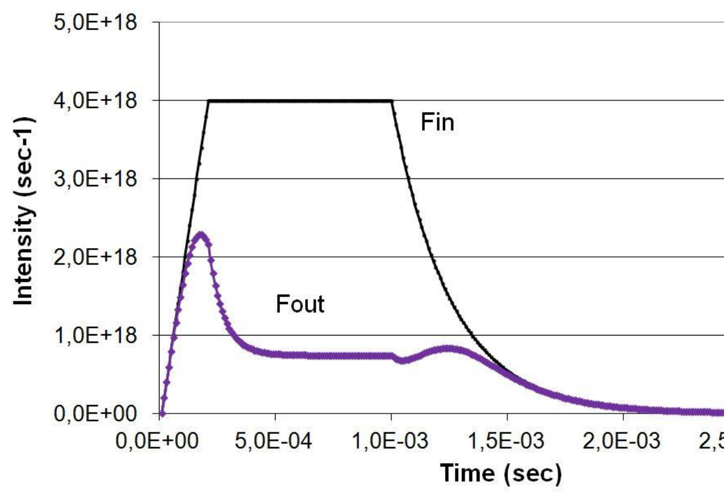


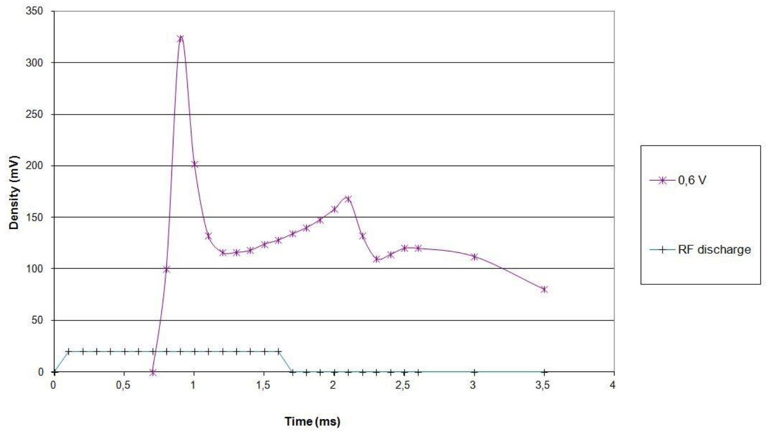
• Atomic hydrogen beam is attenuated passing through the “cloud” due to scattering

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

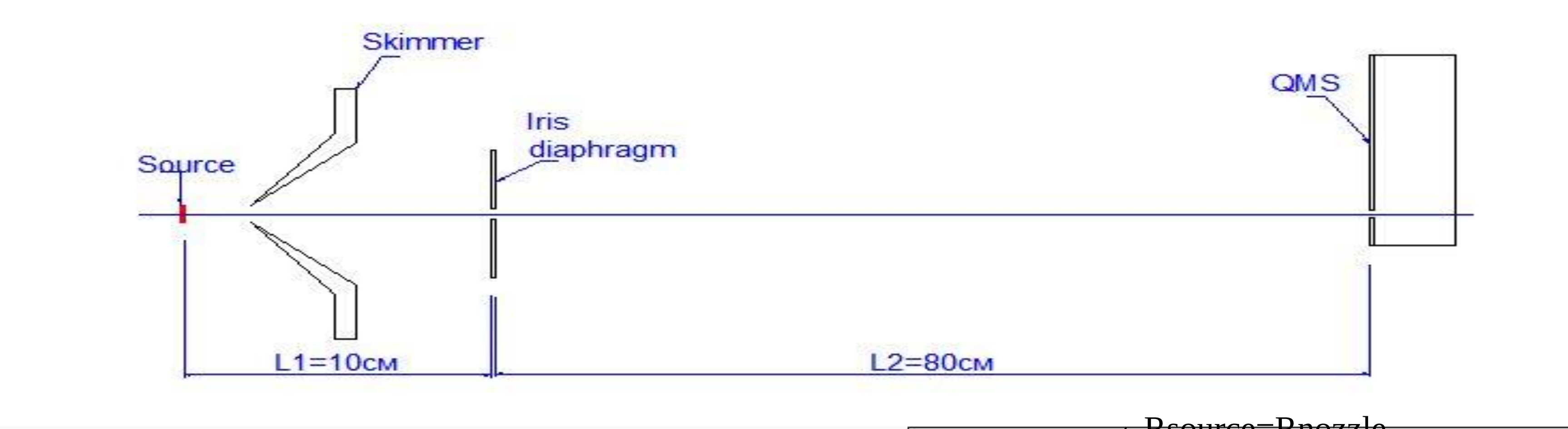
•This process can be one of the reason for ABS intensity limitation because secondary source produces beam with large transversal emittance

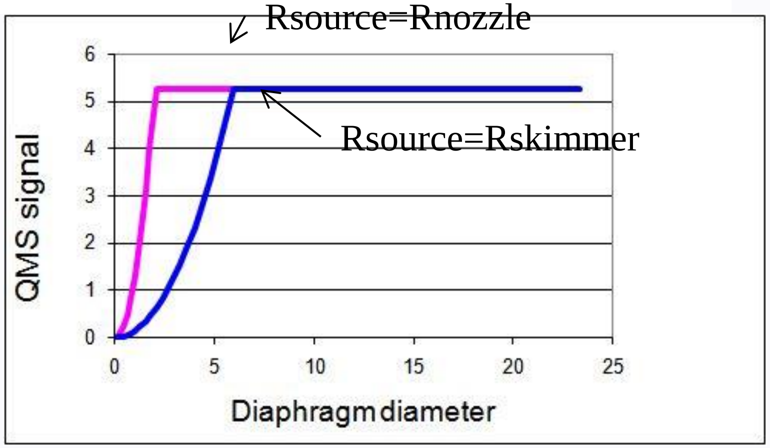
Model calculation for beam – skimmer (beam-“cloud”) interaction





Schematic of apparatus for hydrogen beam source size measurements (PSTP 2011)





Nozzle radius =1.25 mm,
Skimmer radius =3 mm

Comparison of

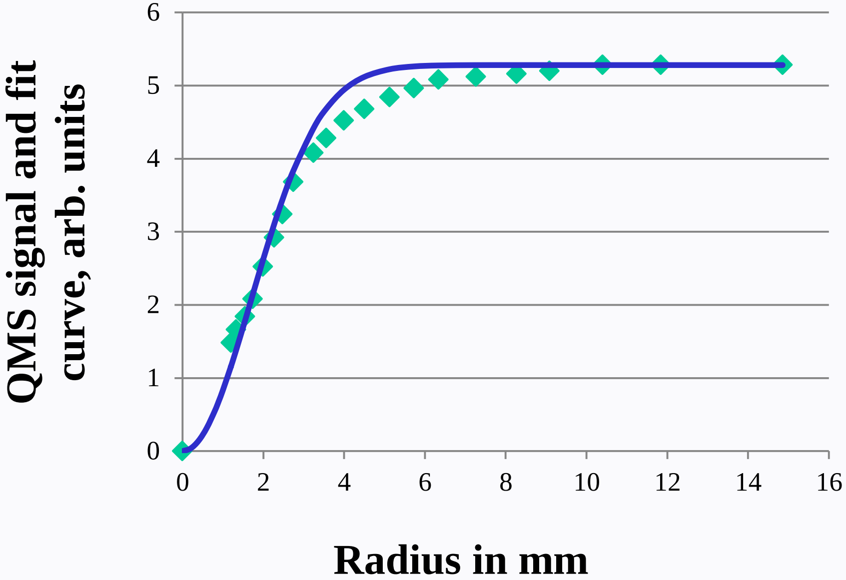
Fit of data by one Gaussian distribution:

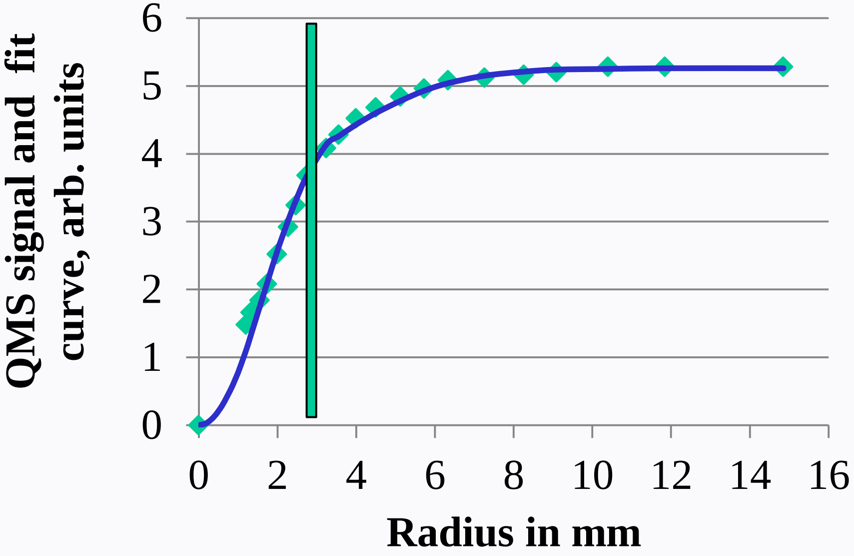
R_1 = 2.4 mm

and

Fit of data by two Gaussian distributions:

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





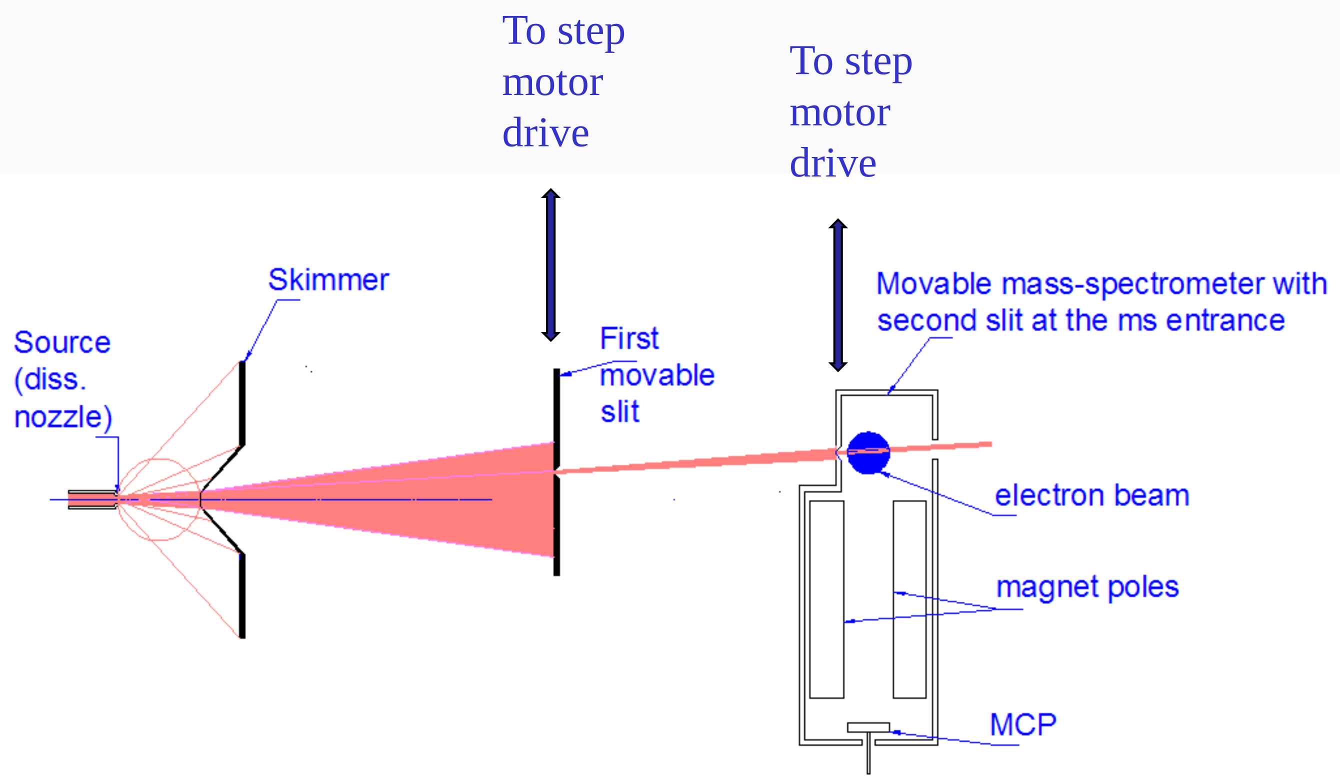
- Increase of size of AB source leads to constrain of AB transversal phase space density and this leads to limitation of intensity of polarized ABS.

- Measurements of atomic source size only is not sufficient.
  It is necessary to measure AB transversal phase space and the phase space density.

- Transversal emittance measurement is routine procedure for ion beams.

- This has not been done so far for atomic beams because it was thought that AB emittance is determined completely by geometric parameters of a beam formation system and it is “in hands” of ABS designers.

Design of Transversal Phase Space Meter for Atomic Hydrogen Beam Source



Formation of atomic/molecular beams

Increasing gas flux into dissociator tube we have different AB formation modes:

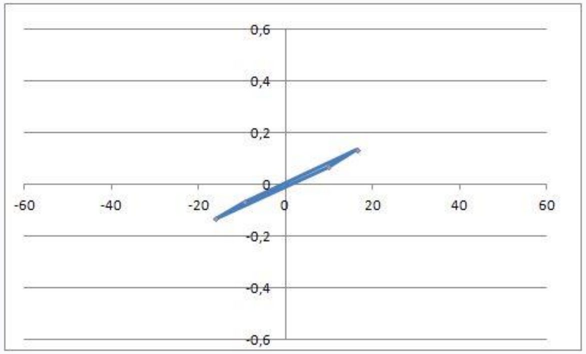
Effusion mode :
- $Kn \geq 1$ (mfp $\geq$ orifice diameter)
- source radius = nozzle radius
- intensity ~ $I_{0max} \sim 10^{18}\ s^{-1}\ ster^{-1}$

Supersonic mode:
- $Kn \ll 1$ (mfp $\ll$ orifice diameter)
- source radius > nozzle radius
- intensity ~ $I_{0max} \sim 10^{19} - 10^{20}\ s^{-1}\ ster^{-1}$

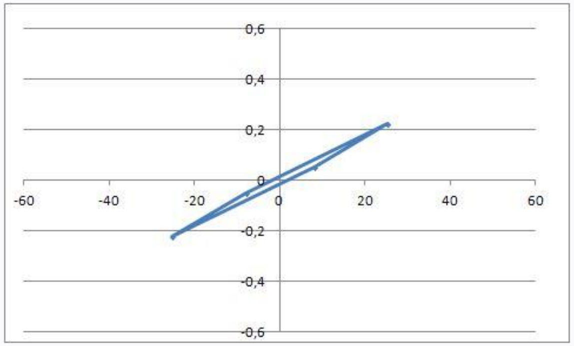
Supersonic mode with intensity limitation:
- primary beam is attenuated due to passage through a pressure bump
- secondary source appears

Comparison of estimated transversal phase-space of atomic hydrogen beam for different mechanism of atomic beam formation

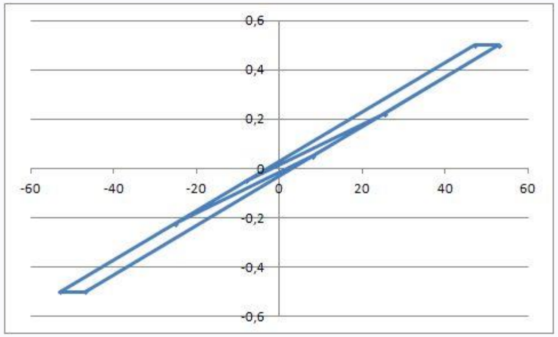
Effusion nozzle



Supersonic nozzle



Supersonic nozzle
+secondary source



Difference in the phase space portraits is due to change of atoms source size and its position . These AB source parameters can be obtained from the emittance pictures. This requires space and angle resolution of the emittance meter of ~ 0.5 mm, 5mrad respectively.

Summary

- Measurements of transversal emittance of atomic hydrogen beam downstream a skimmer of ABS would produce valuable information about mechanism of atomic beam formation and for design of optimal sextupole magnet system. Space and angle resolution of the emittance meter should be around 0.5 mm and 5 mrad respectively.

- The AB emittance meter should help resolve the question:

  Is transversal phase space density of AB downstream the beam formation system limited or not?

- This will give a guide line to further optimization of the ABS.