# Limits on the Intensity of Polarized Atomic Beam Sources


Dmitriy Toporkov

Budker Institute of Nuclear Physics

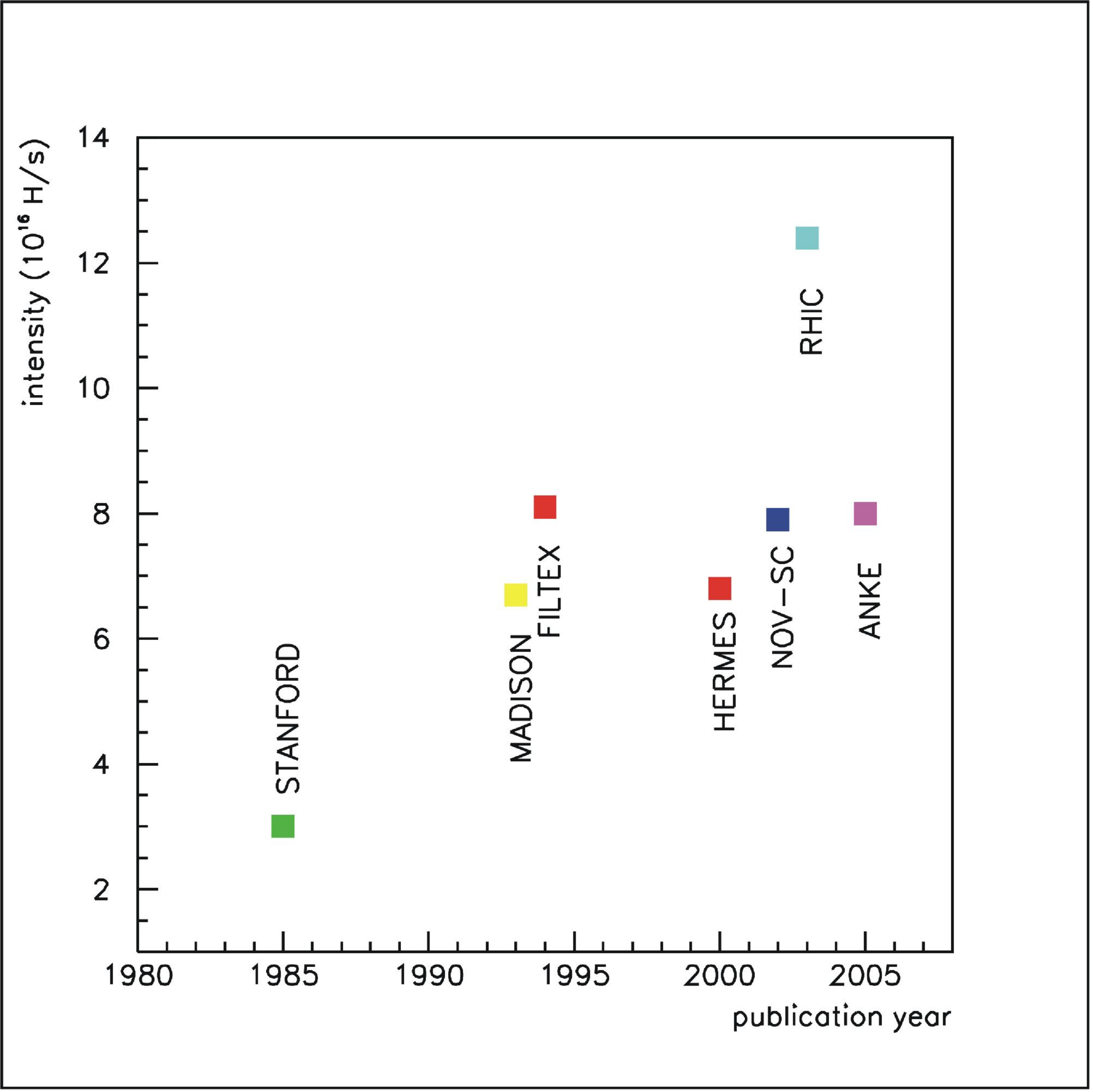
Novosibirsk, Russia

Ferrara University, Italy


October 29,2007

# *CONTENTS*

- **Introduction**
- **Attenuation by residual gas and pressure bump**
- **Shielding effect of skimmer**
- **Intra beam scattering**
- **Atomic beam focusing at different flow rate**
- **What to measure further?**
- **Conclusion**




**M.Stancary et al.**

$$\frac{dI(\theta)}{d\Omega} = \frac{Q_0}{\pi}\frac{(n+1)}{2}\cos\theta^n = I_0 \cos^n(\theta)$$

$$I_{foc.} = \alpha\ I_0\ \pi\ \theta_{max}^2\ \ T\ \ (1\text{-}Att)$$

$\alpha$ – atomic fraction

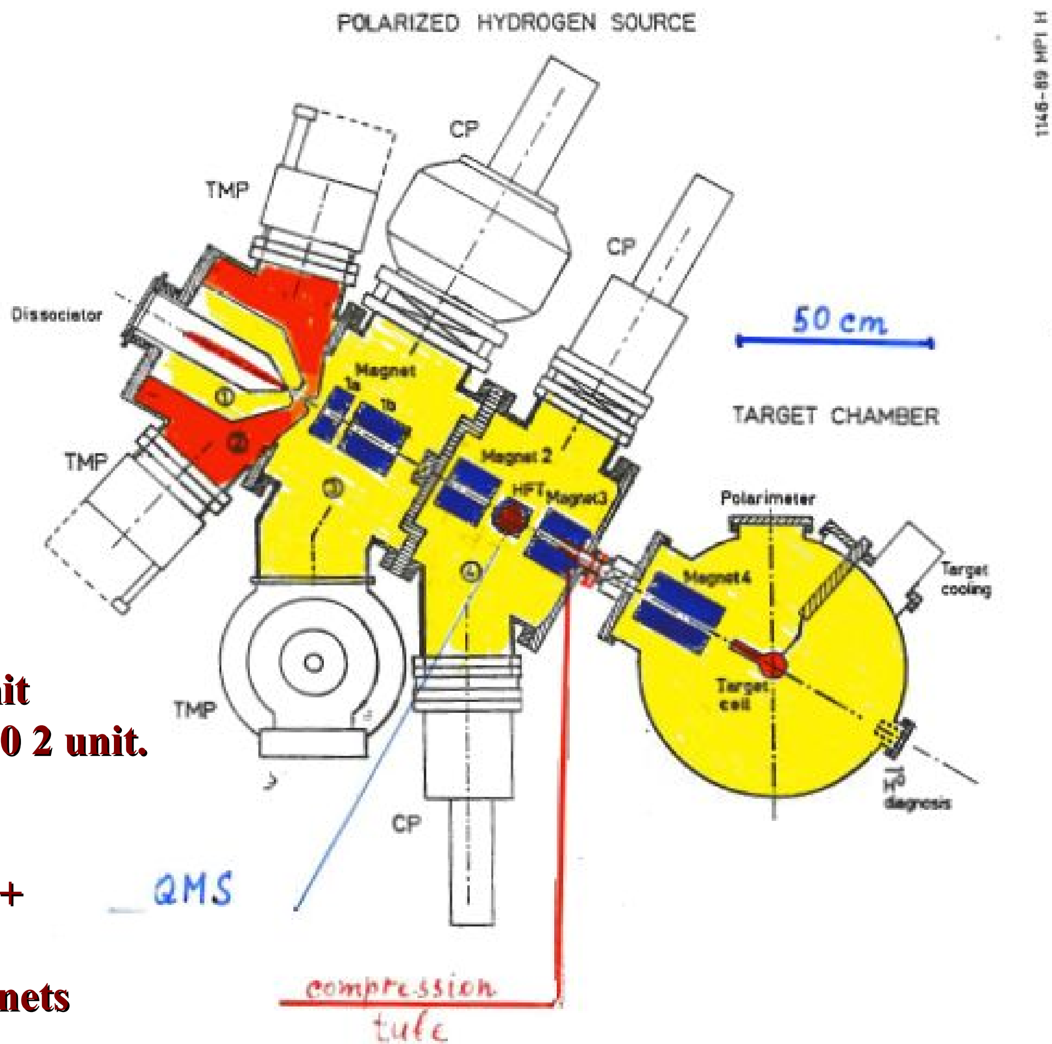
$T$ – transmission factor

$(1 - Att)$ – attenuation due to residual gas scattering

$\pi\theta_{max}^2$ – maximum accepted solid angle

$$\lambda = (\sigma n)^{-1}$$

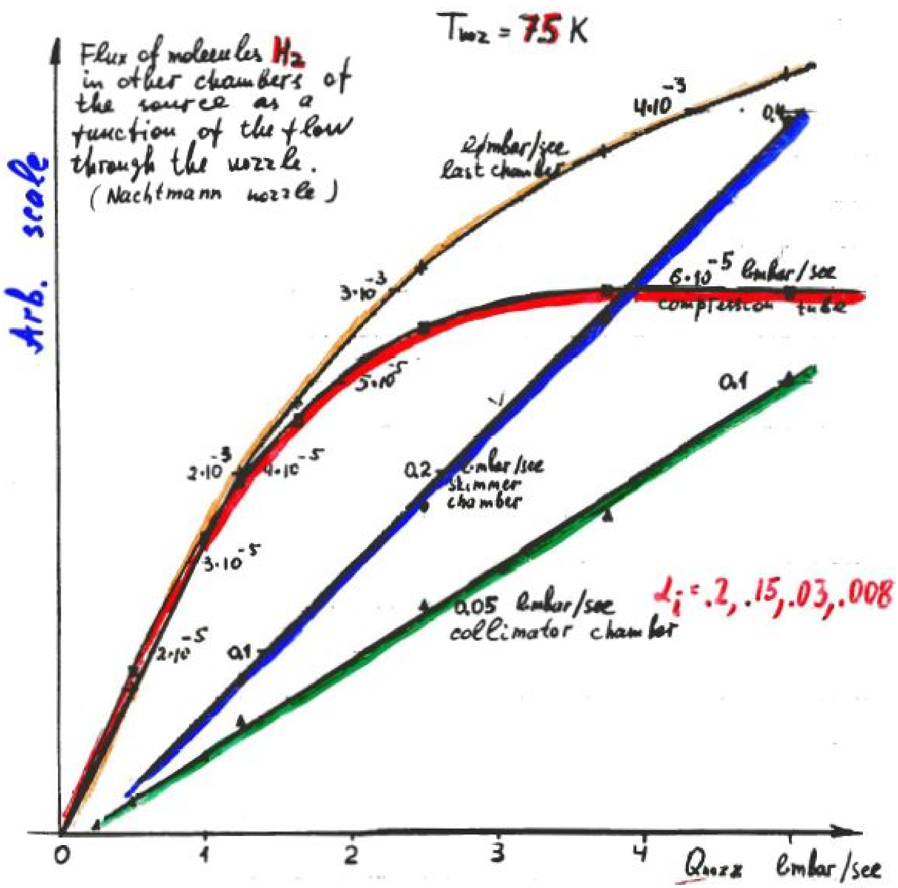
# Formation of the atomic or molecular beam

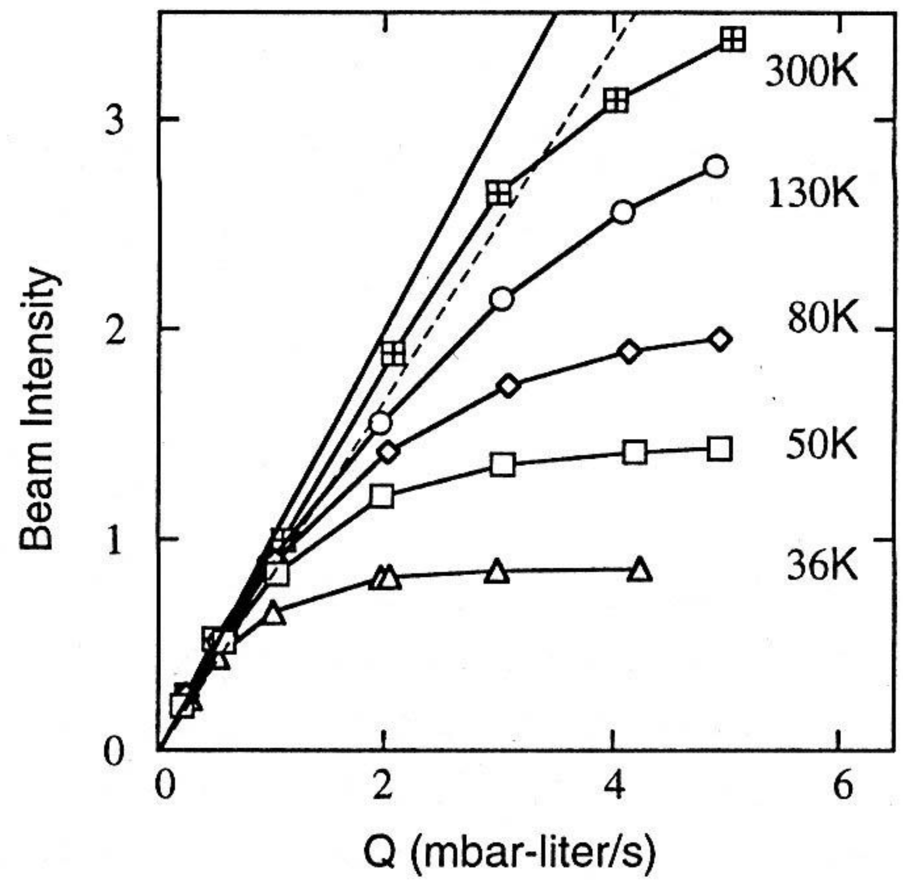



**BALZER TMP 2200 2 unit**
**LEYBOLD-HERAUS 1000 2 unit.**
**BALZERS TMP 2200 +**
**KRYOPUMP 3500**
**KRYOPUMP 1500 2 unit +**
**TMP 360**
**Permanent sextupole magnets**
**B = 1.5T**

# Intensity of the $H_2$ molecular beam ( free beam )

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



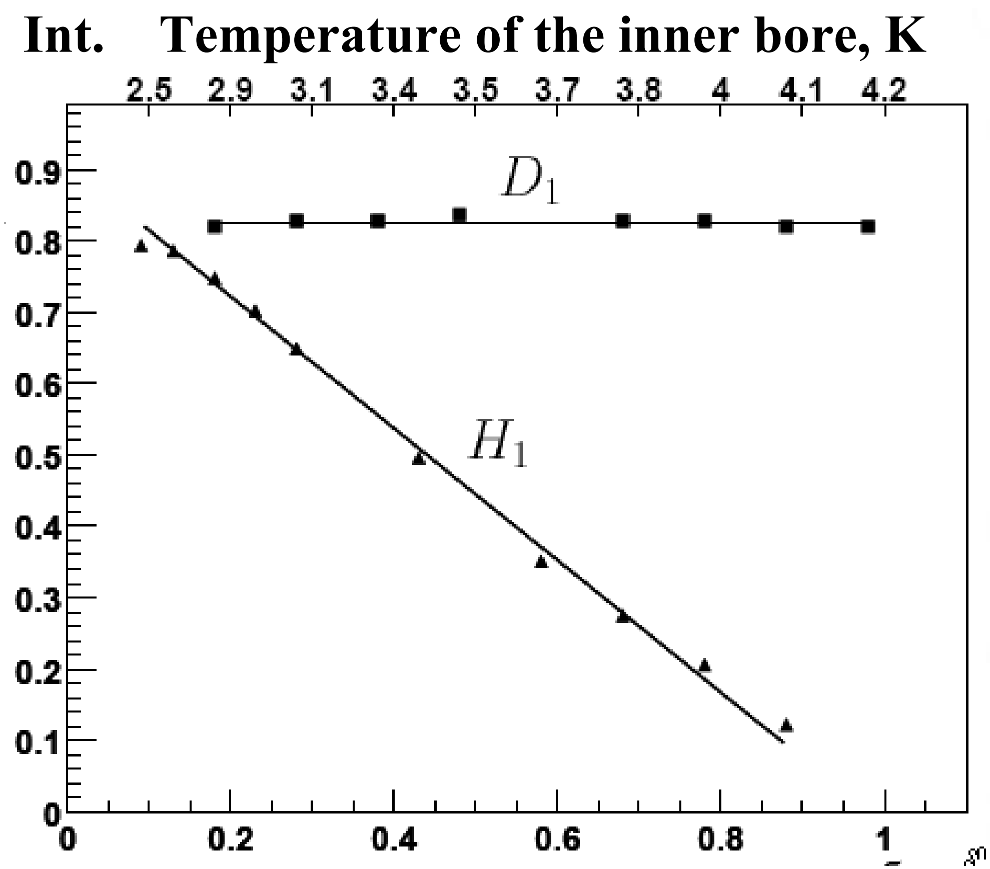
# Attenuation of the beam inside the magnets

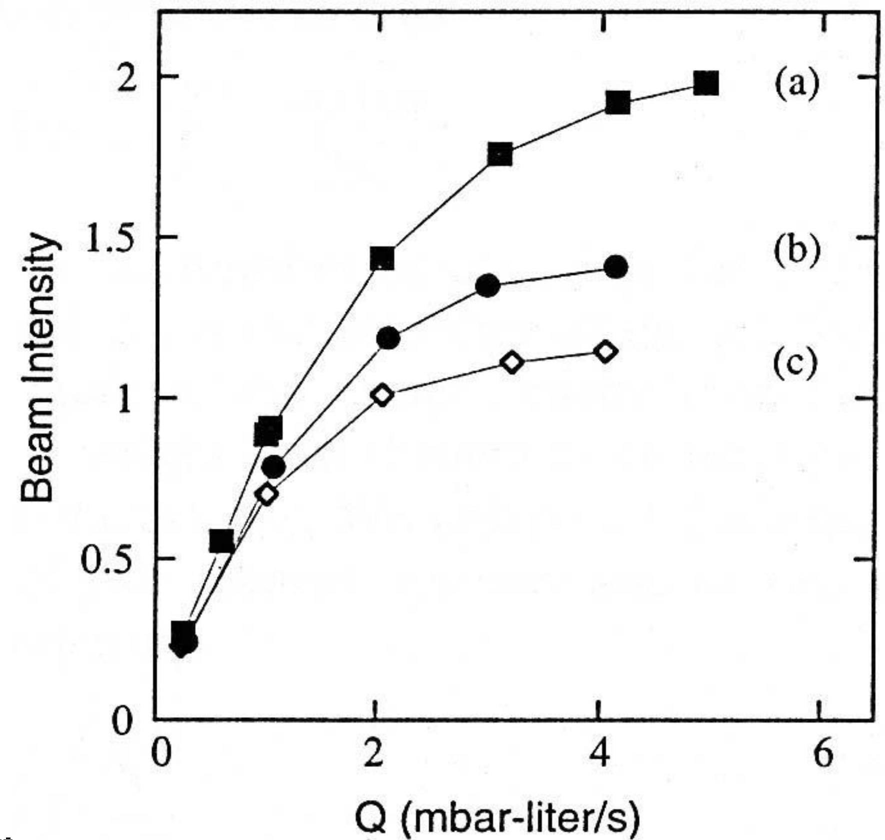
*M.V.Dyug  et al. NIMA 495/1 (2002) 8_*

*$H_1$ beam ,  cryogenic magnets system*

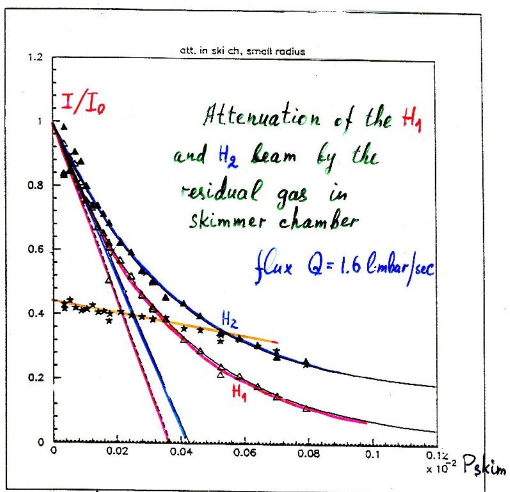
*T.Wise et al. NIMA 336(1993) 410*

*$H_2$ beam ,  dummy magnets system for $H_1$ beam attenuation should be larger*

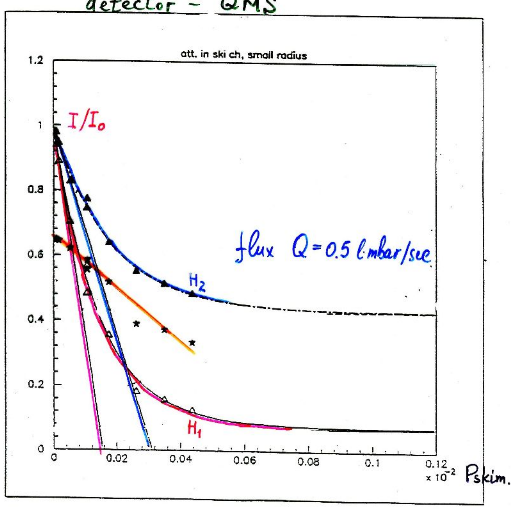


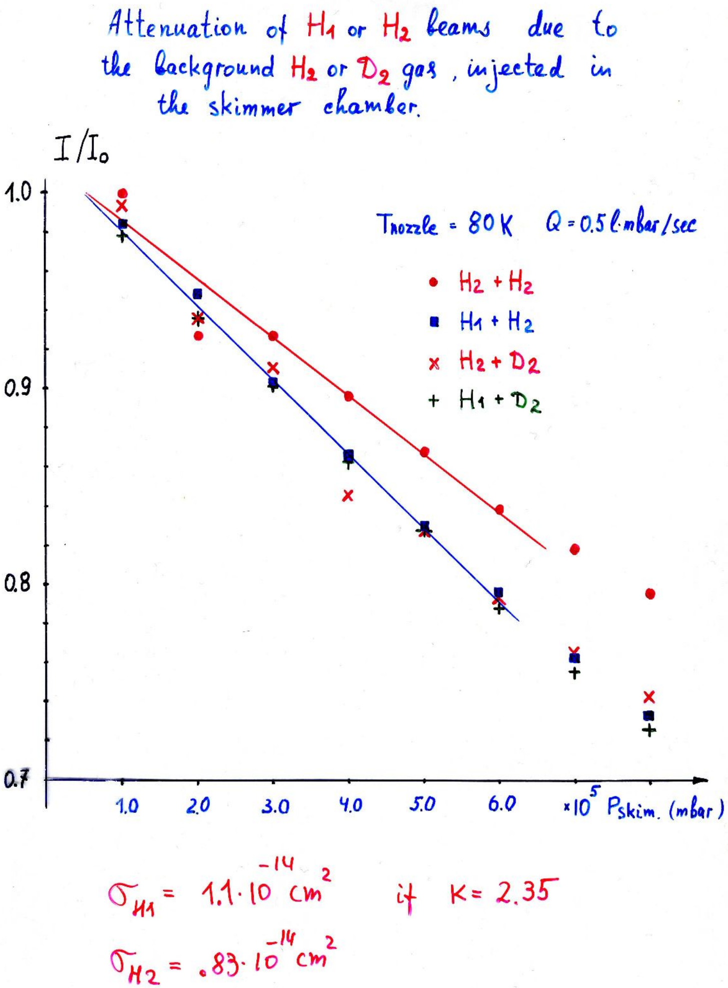



# Attenuation of the beam by residual gas - well understood process



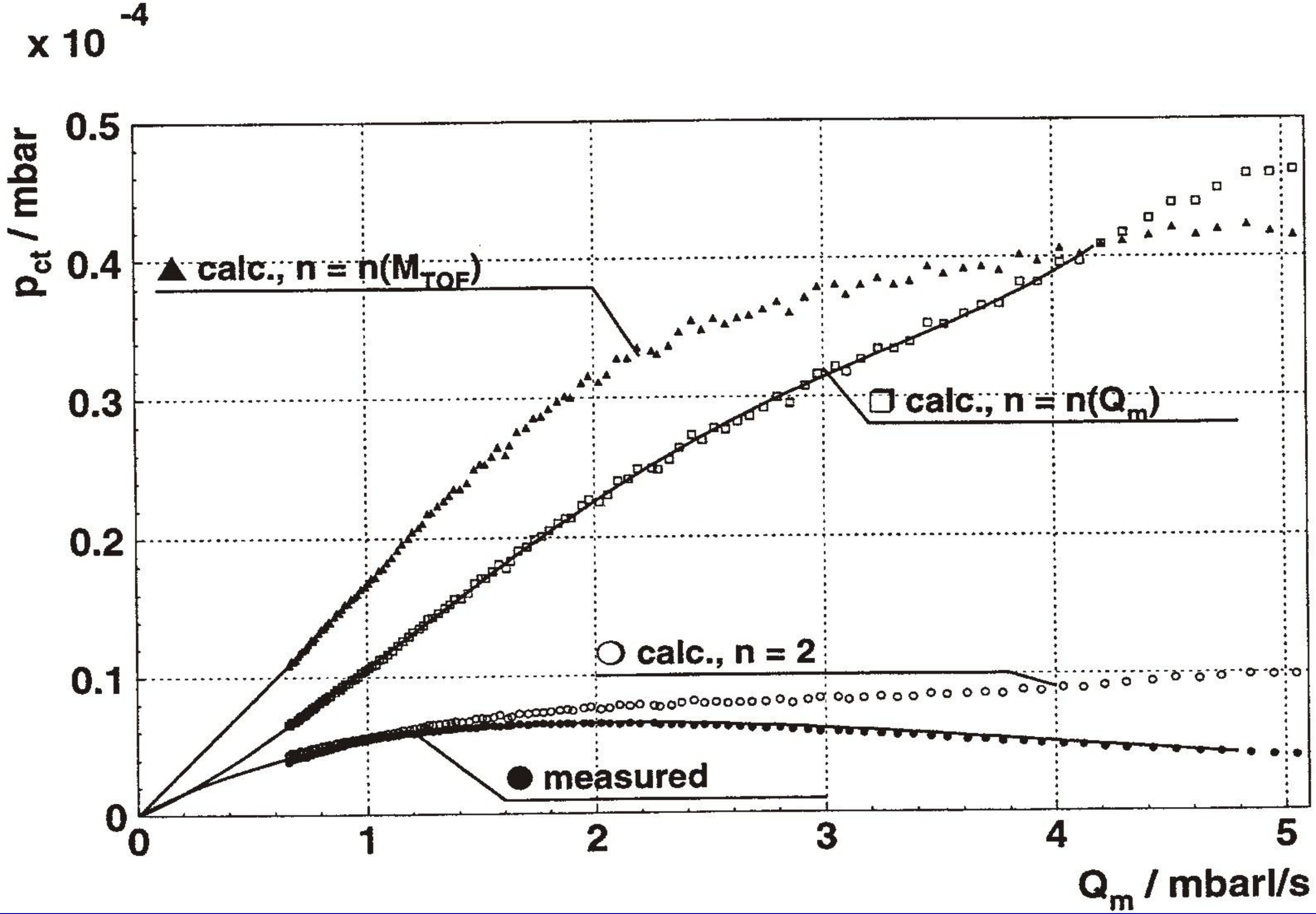

detector – QMS



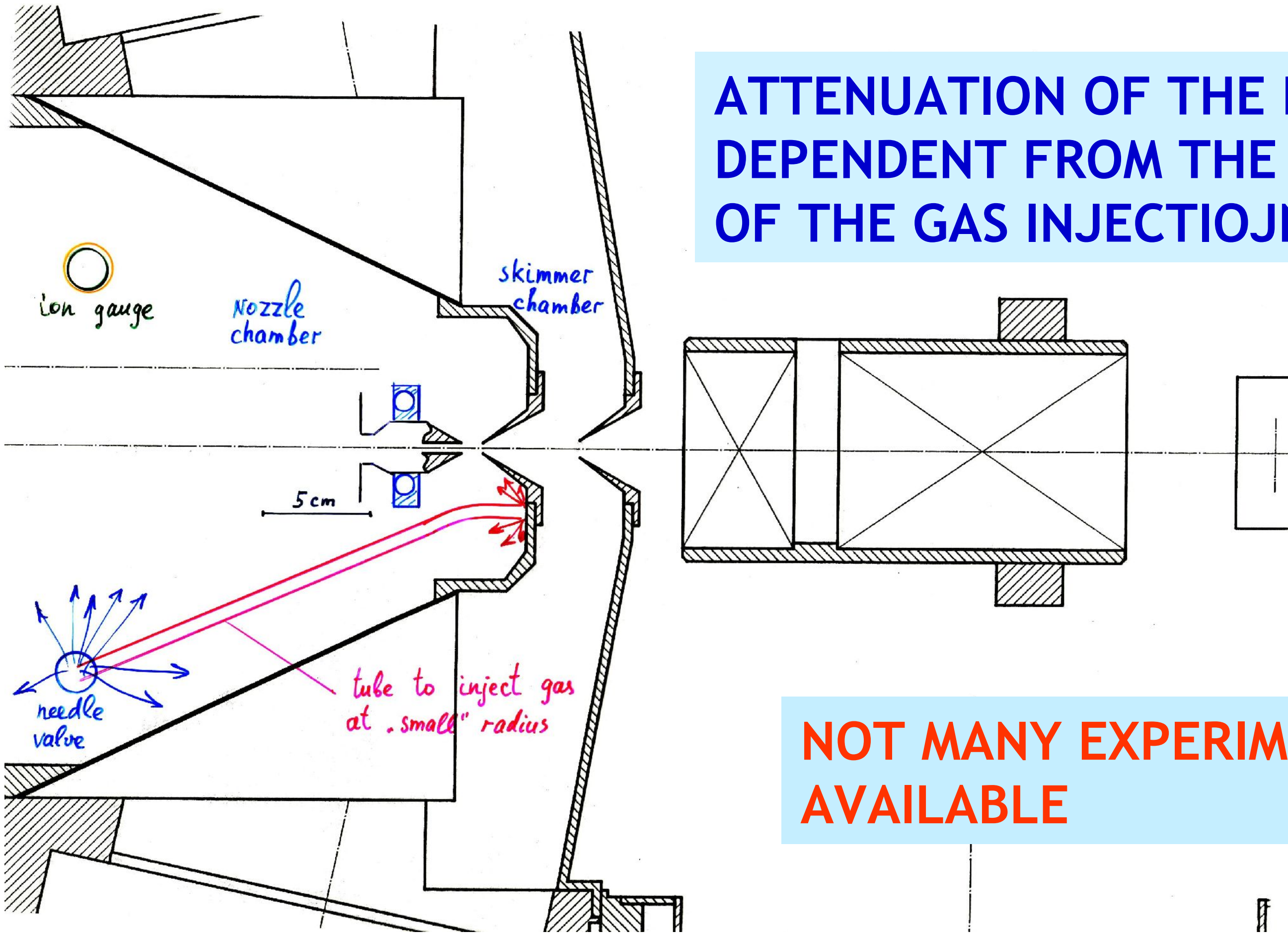




$$I(p) = I_0 * \exp( -x * p/(\lambda_0 p_0))$$

***Relative velocities of particles correspond room temperature***



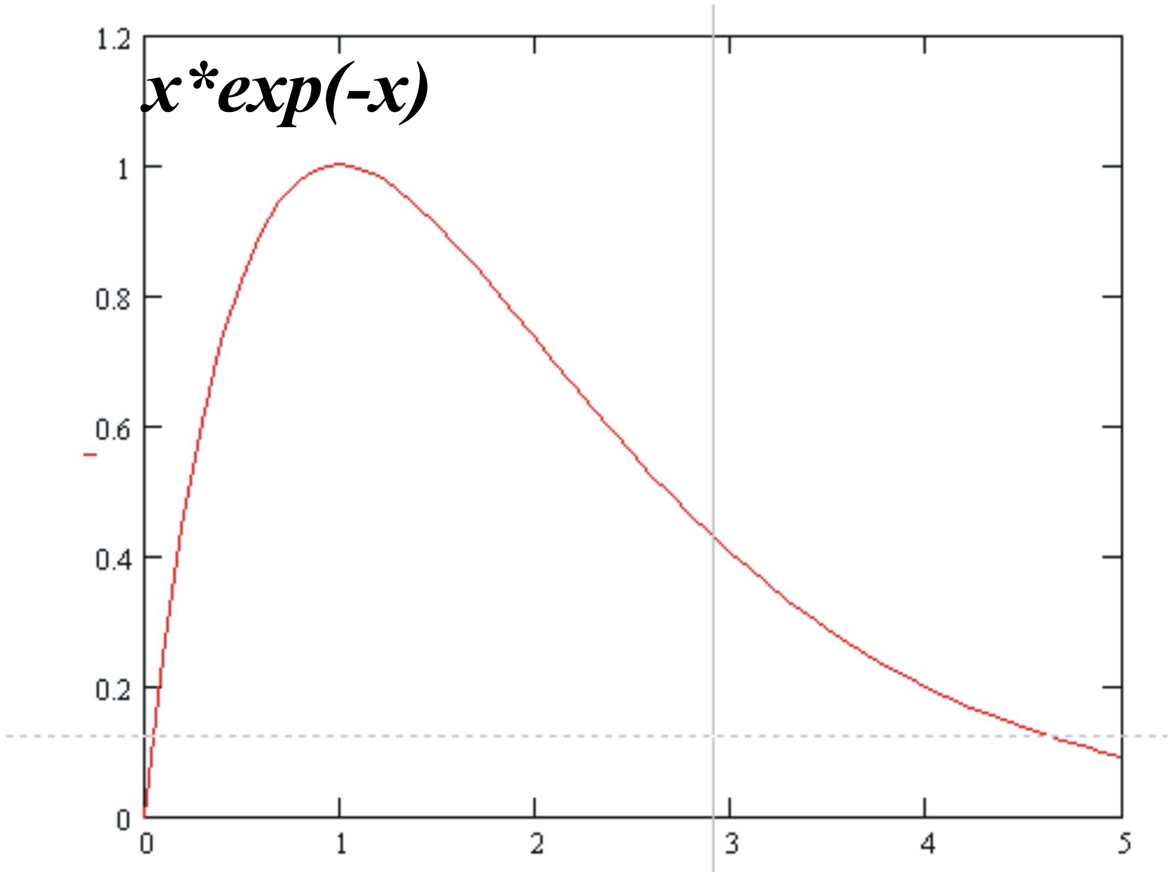

**Dependence of the pressure rise in the compression tube on the nozzle throughput for a molecular deuterium beam at a nozzle temperature 100 K. Shown are the measured values (full dots), and those calculated for various peaking exponent. [ N. Koch. A study on the Production of the Intense Cold Atomic Beams for Polarized Hydrogen and Deuterium Targets. DESY-THESIS-1999-015, 1999.]**




**ATTENUATION OF THE BEAM IS DEPENDENT FROM THE POSITION OF THE GAS INJECTIOJN**

**NOT MANY EXPERIMENTAL DATA AVAILABLE**

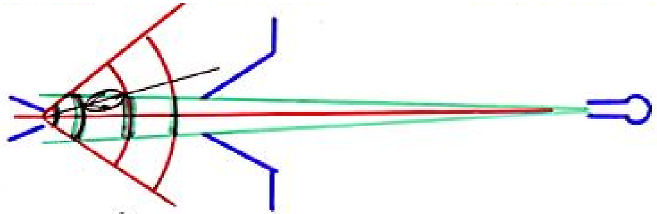
$$I(Q)=a*Q_0*(Q/Q_0)*exp(-Q/Q_0)=a*Q_0*x*exp(-x)$$

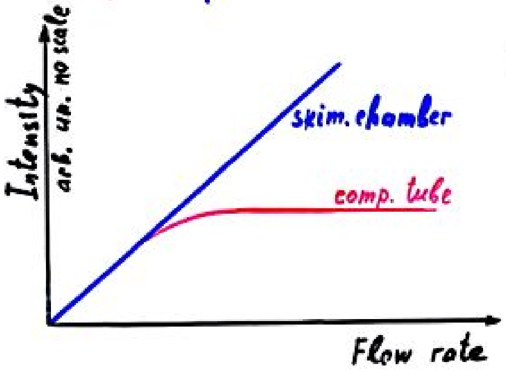


# *Two effect which may to provide saturation of the intensity*

**Saturation of the intensity at large distance**

**Nozzle skimmer detector**





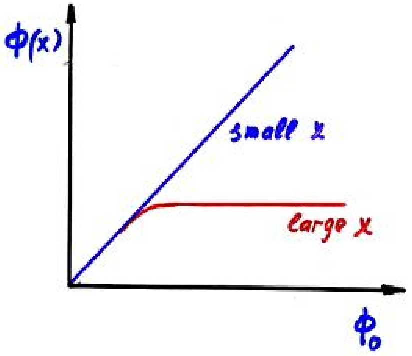

INTRA BEAM SCATTERING

Zankel K. 1972 J.Phys. B: Atom.Molec.phys. 5,74-9.

$$d\Phi = -\alpha\Phi^2 dx$$

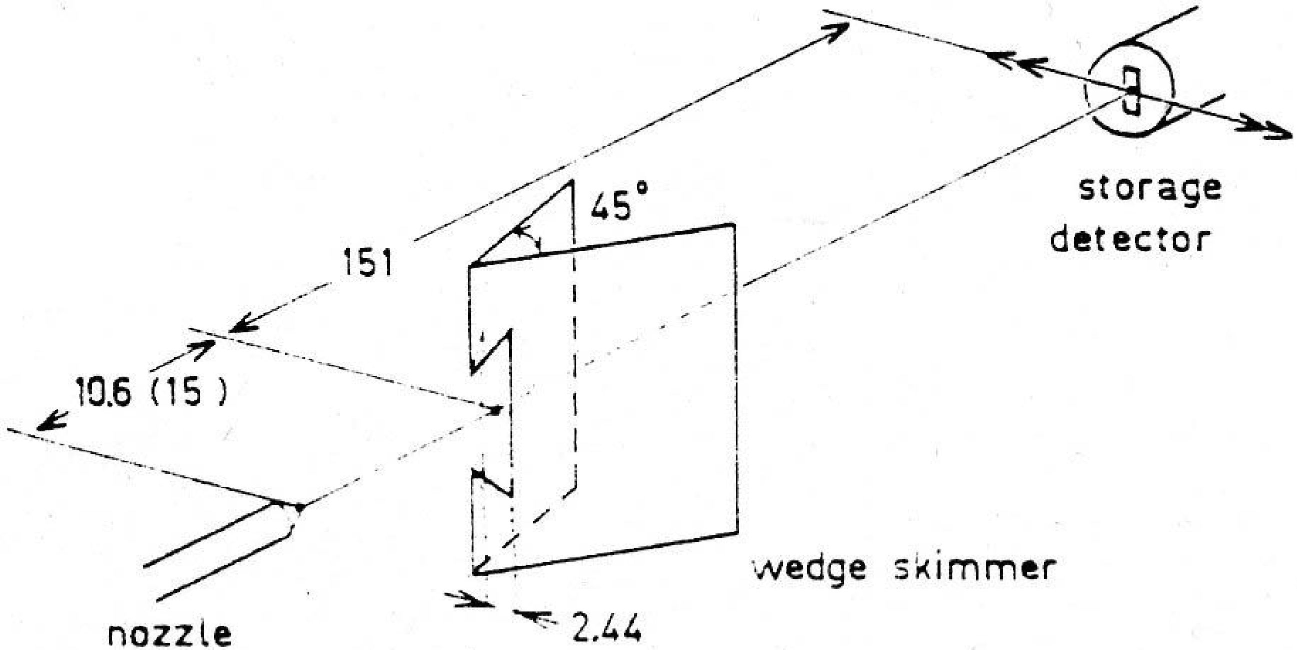
$$\alpha \approx \frac{\Delta v \cdot \sigma}{v_{max}^2}$$

$$\Phi(x) = \frac{\Phi_0}{1 + \alpha \cdot \Phi_0 \cdot x}$$




**Shielding by the skimmer**

# Geometry of the experiment




Schematic view of the beam profile measurement.
The whole assemble is contained in a 20K cryochamber.
Detector slit dimensions are 2.0x0.5 $mm^2$ in a 0.5 mm thick wall.

*H.C.W.Beijerinck and N.F.Verster Physica 111C(1981)327-352*

# Shielding effect of the skimmer

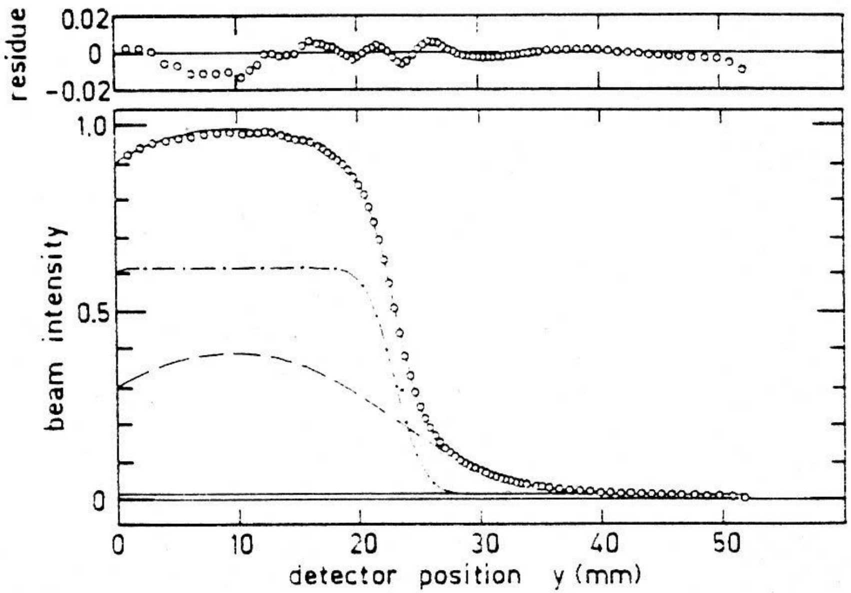



Fig. 9. Measured beam profile for nitrogen at $\Xi = 76.3$ (data points) and the curve fit with the model function of eq. (41) (solid line). The contributions of the narrow virtual source (dash-dotted line), the wide virtual source (dashed line) and the constant background are indicated separately. The experimental data have been corrected for the position dependent solid angle of the detector (see section 6.2).

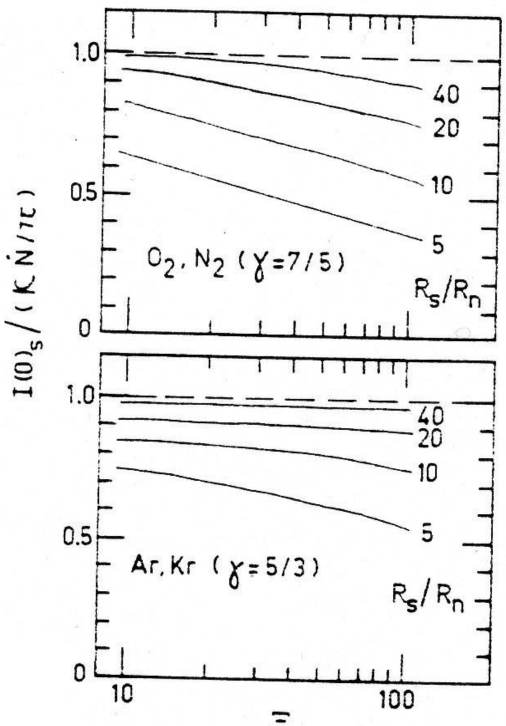
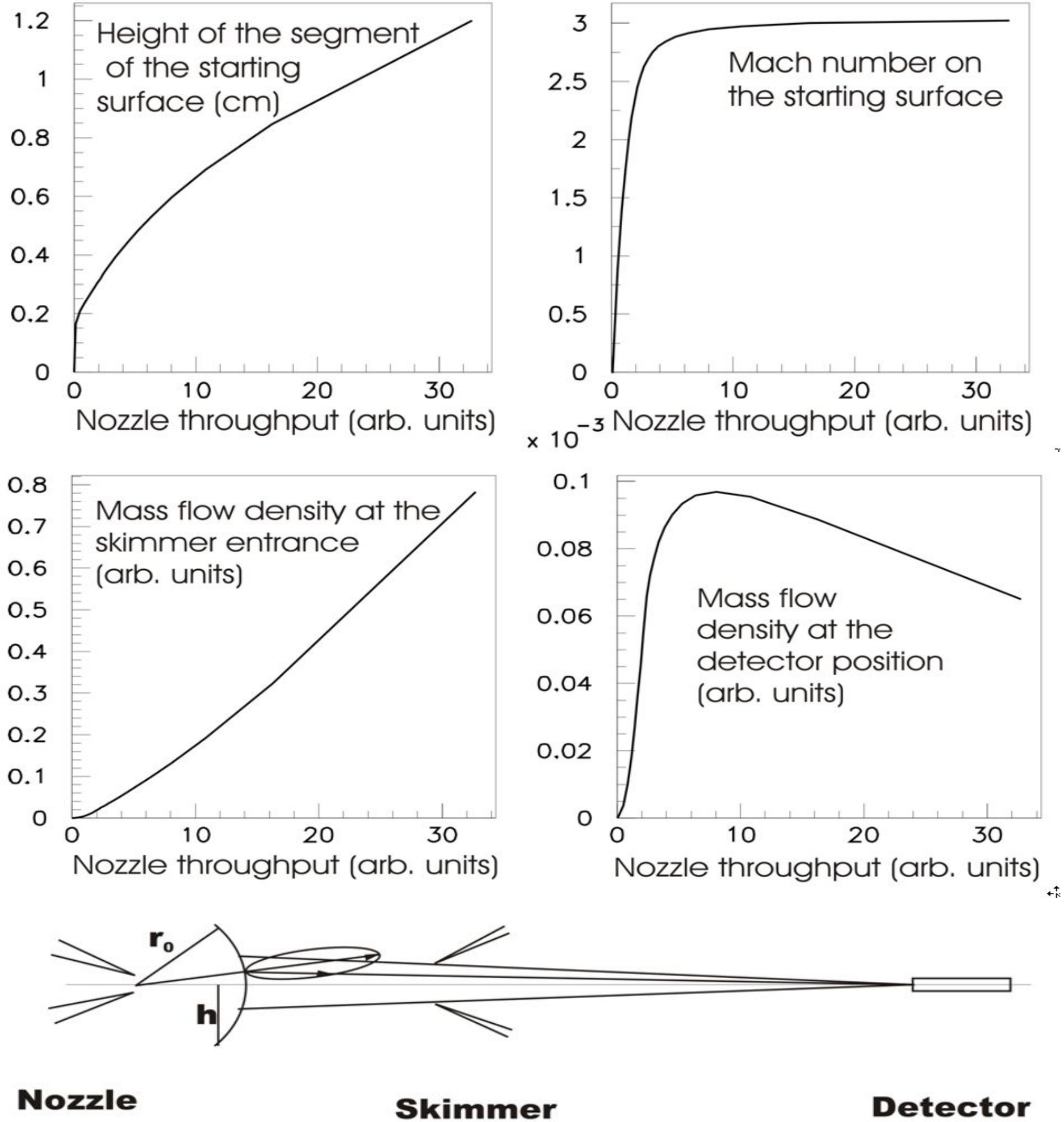



Fig. 13. Calculation of the shielding effect of the skimmer with the experimental results of table III. The design rules $R_s/R_n = 20$ and $R_s/R_n = 40$ for monoatomic and diatomic gases ($\gamma = 7/5$), respectively, result in $I(0)_s/(\kappa\dot{N}/\pi) \geq 0.90$ for $\Xi \leq 100$.

**For Ar at 300K** $\quad \Xi = \mathit{0.161Kn^{-1}} = 0.174\,Re = 29.7(\mathrm{Torr^{-1}\,cm^{-1}})P_0D_{noz.}$




**S.V. Musanov. Scientific Proc. of TsAGI, v.III, N.4 (1972) 130. In Russian.**

**D.K.Toporkov. Nuclear Instruments and Methods in Physics Research A536(2005)255**

*For parallel beam and Δv being the velocity spread*

$$\Phi(x) = \frac{\Phi(0)}{1+\alpha\ \Phi(0)\ x} \qquad \alpha = \frac{\Delta v\ \ \sigma}{v_{max}^2}$$

$\Delta v/v_{max} \sim 0.25 \quad v_{max} \sim 2*10^5\ cm/sec$

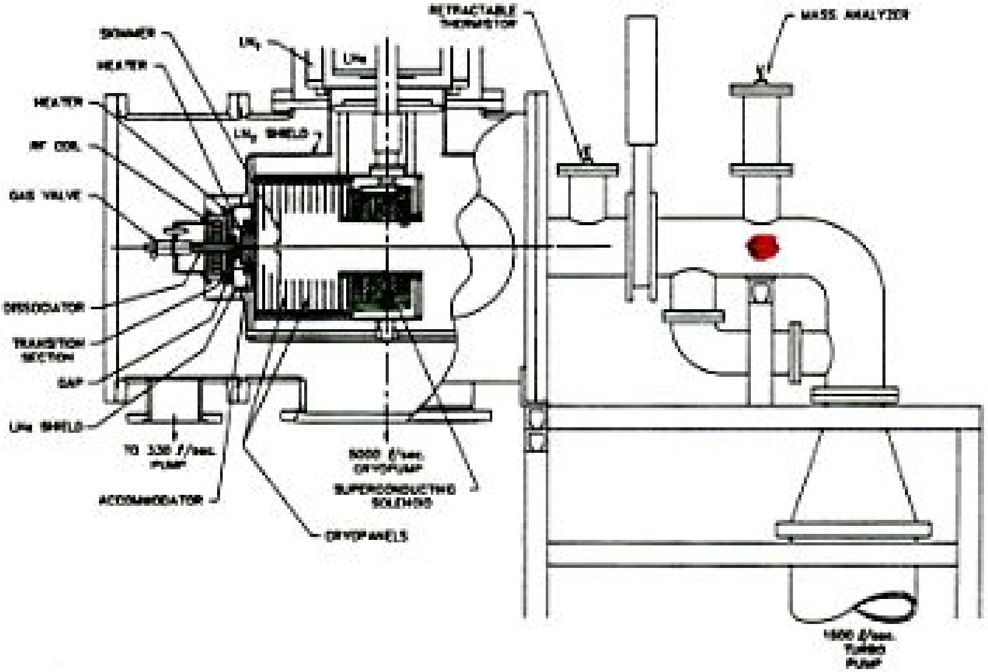
**$\sigma$~ $1.5*10^{-14}cm^{-2}$** **this is from attenuation atomic beam by 300K residual gas**

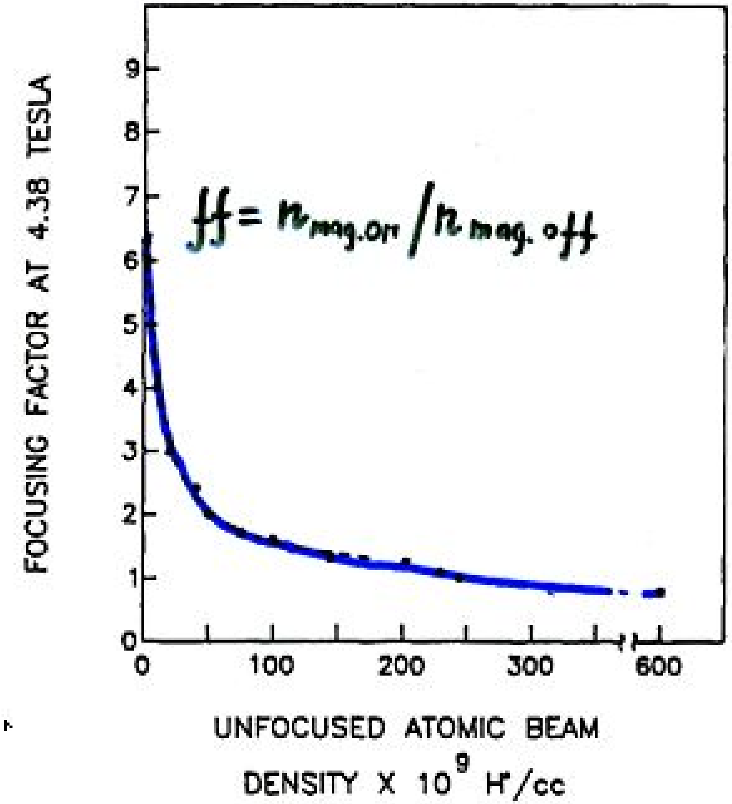
**For 20K beam temperature σ should be larger**

**For given σ α ~ $2*10^{-20}$ cm*sec**

$$\Phi(150cm) \quad 0.8\ \ \Phi(0) \qquad\qquad \Phi(x) \quad \frac{1}{\alpha\ \ x}$$

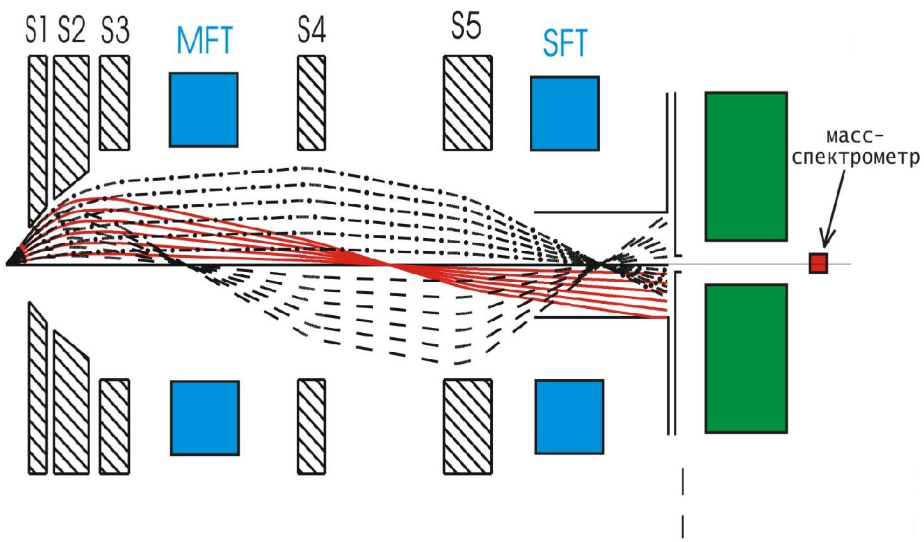
# A.Hershcovitch. Phys.Rev.Lett. 63(1989)750




***Tremendous pumping speed of about 40000 l/sec for $H_2$ at 2.5 K temperature***

# Focusing magnets

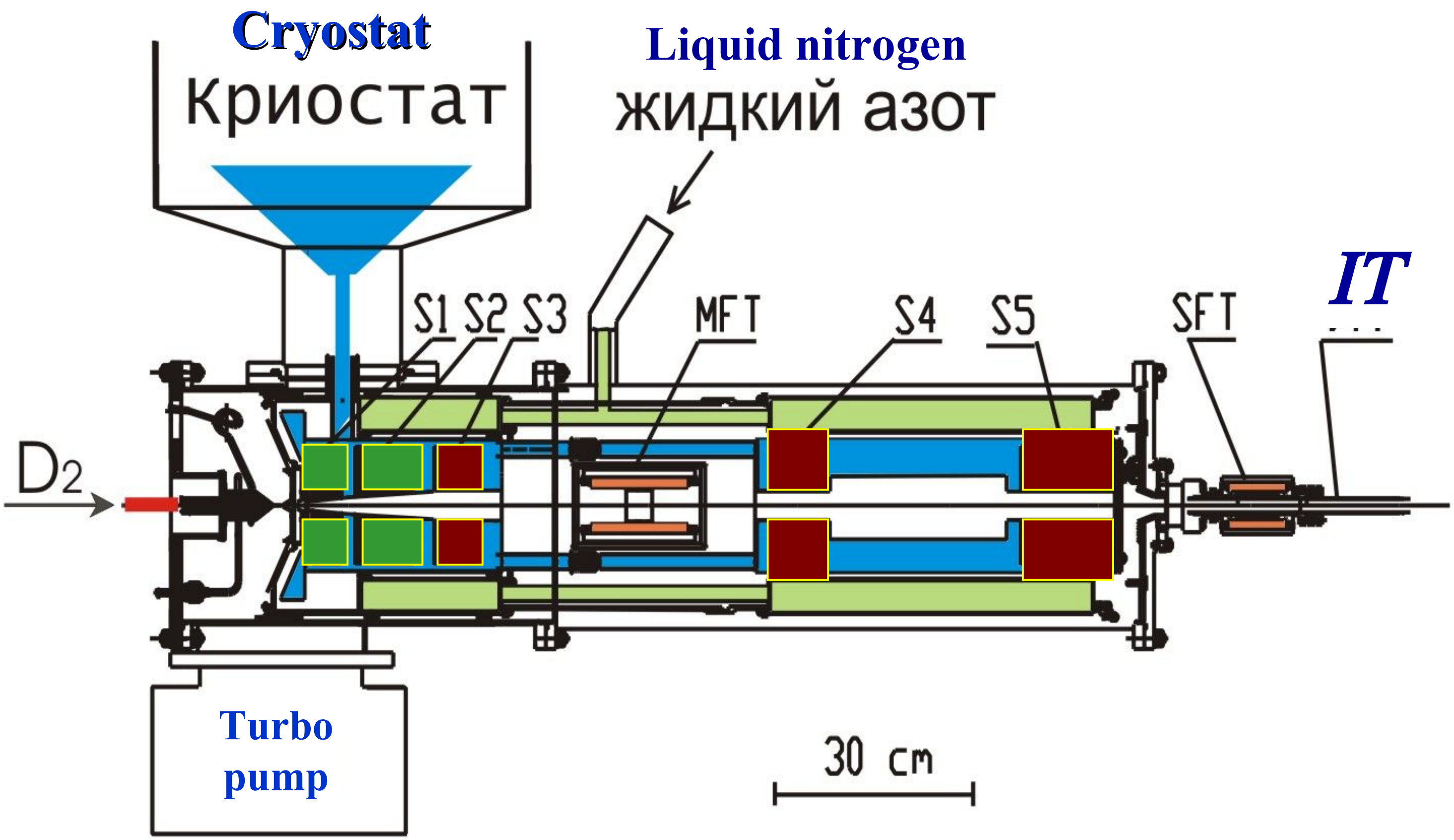


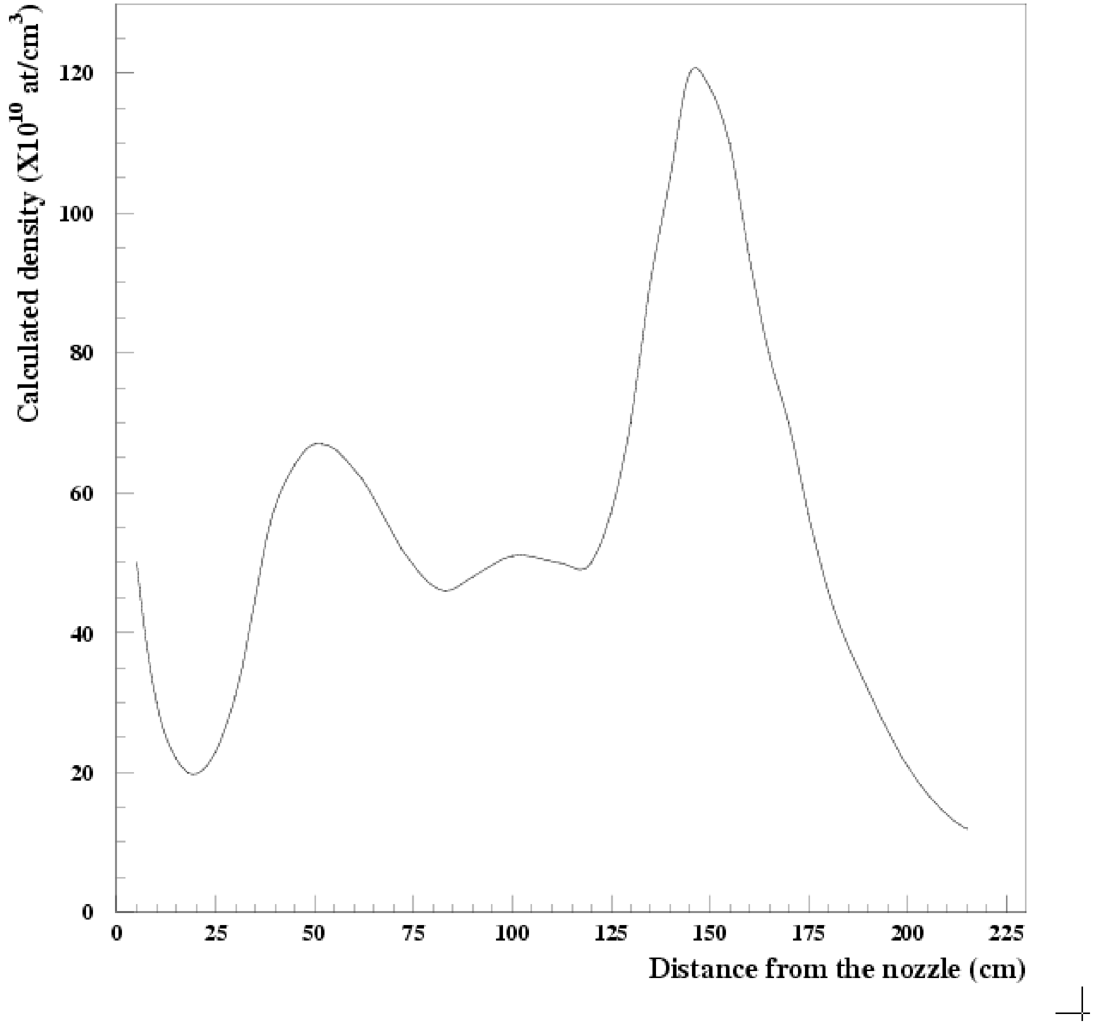

**Permanent magnets**
**B=1.6 T**
**Superconducting**
**B=4.8 T**

$$\Delta\Omega = \pi * \alpha^2 = \pi * \mu * B / \kappa T$$

| | | |
|---|---|---|
| $B = 1.6\ T$ | $\Delta\Omega \sim 1.5 * 10^{-2}\ sr$ | $\alpha \sim 0.07\ rad$ |
| $B = 4.8\ T$ | $\Delta\Omega \sim 4.5 * 10^{-2}\ sr$ | $\alpha \sim 0.21\ rad$ |

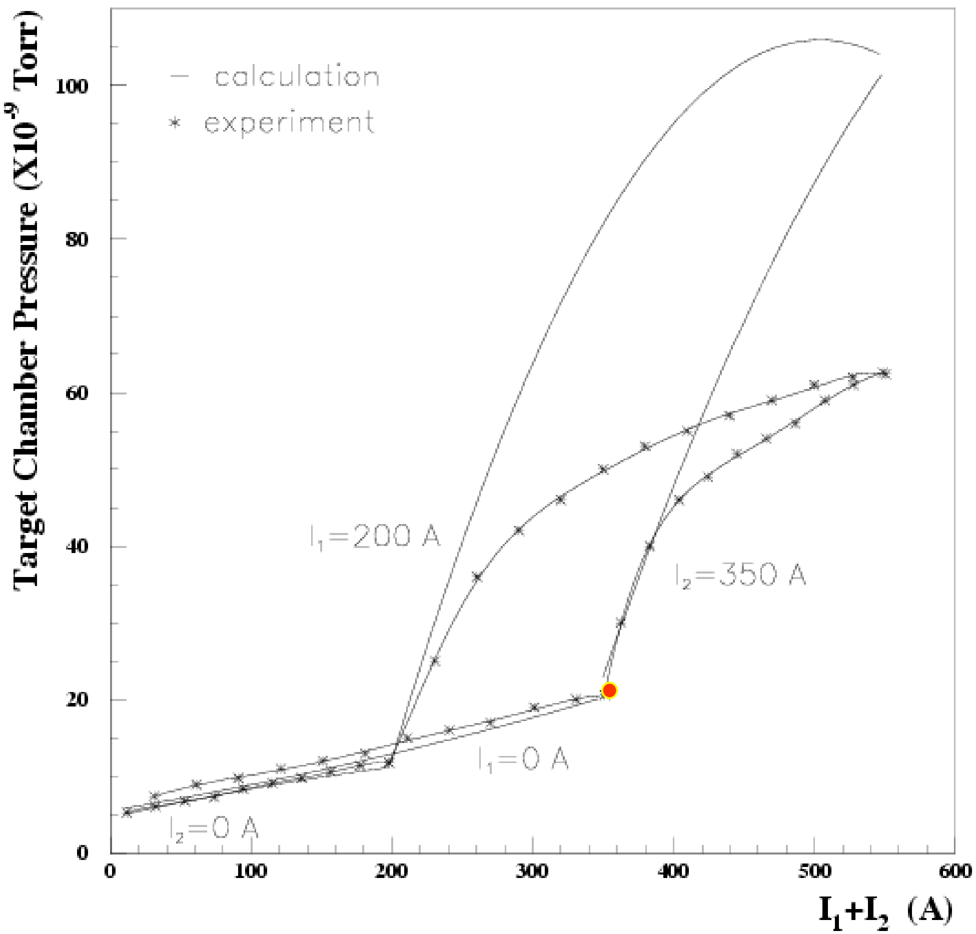
**Two group of magnets – green (tapered magnets) and red (constant radius) driven independently, 200 and 350 A respectively**



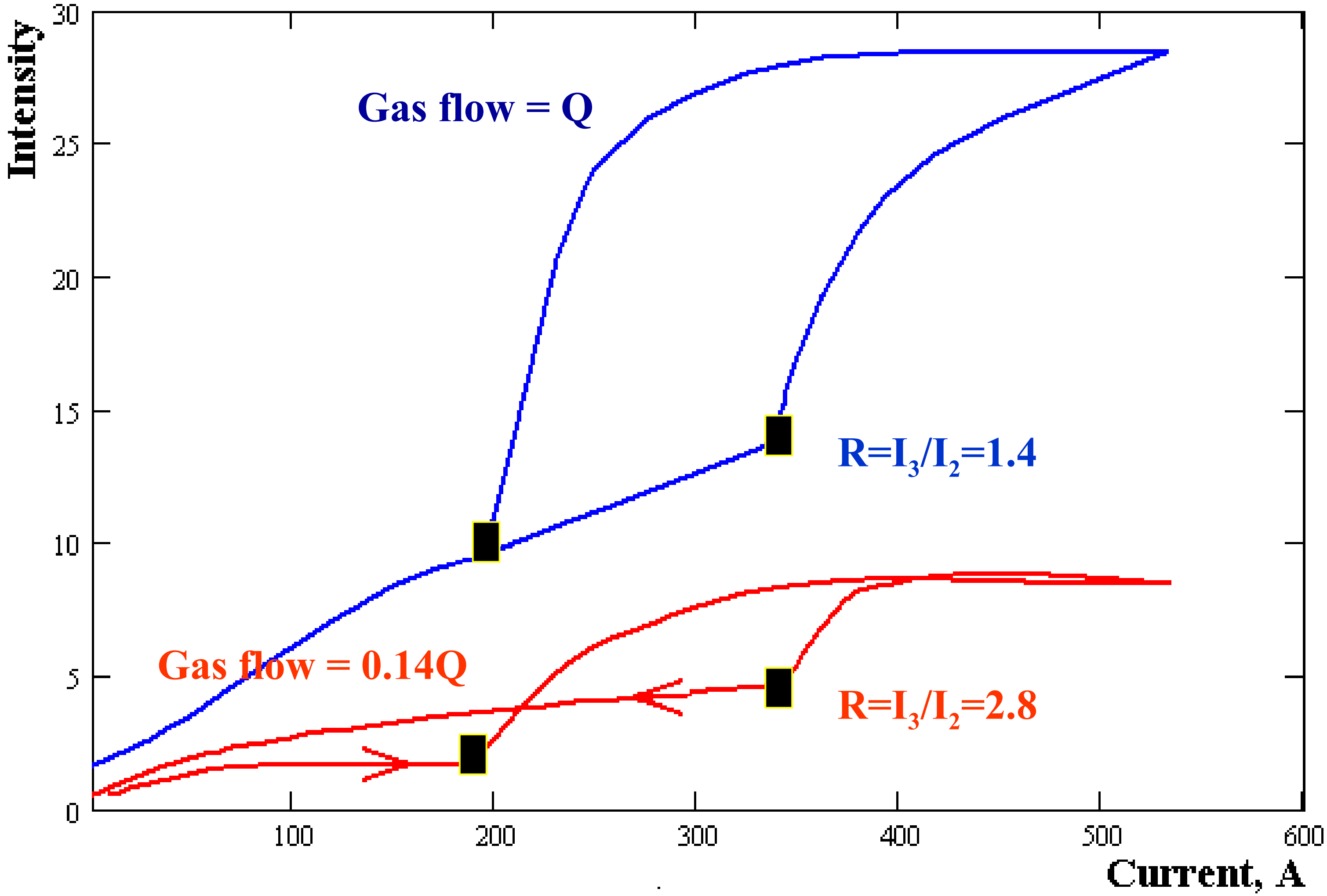



# Calculated density along the source axis in 1 mm radius

**Intensity of the atomic beam vs current through the coils. The measured value is vacuum in the straight section of the VEPP-3 storage ring. Beam is injected into the storage cell.**

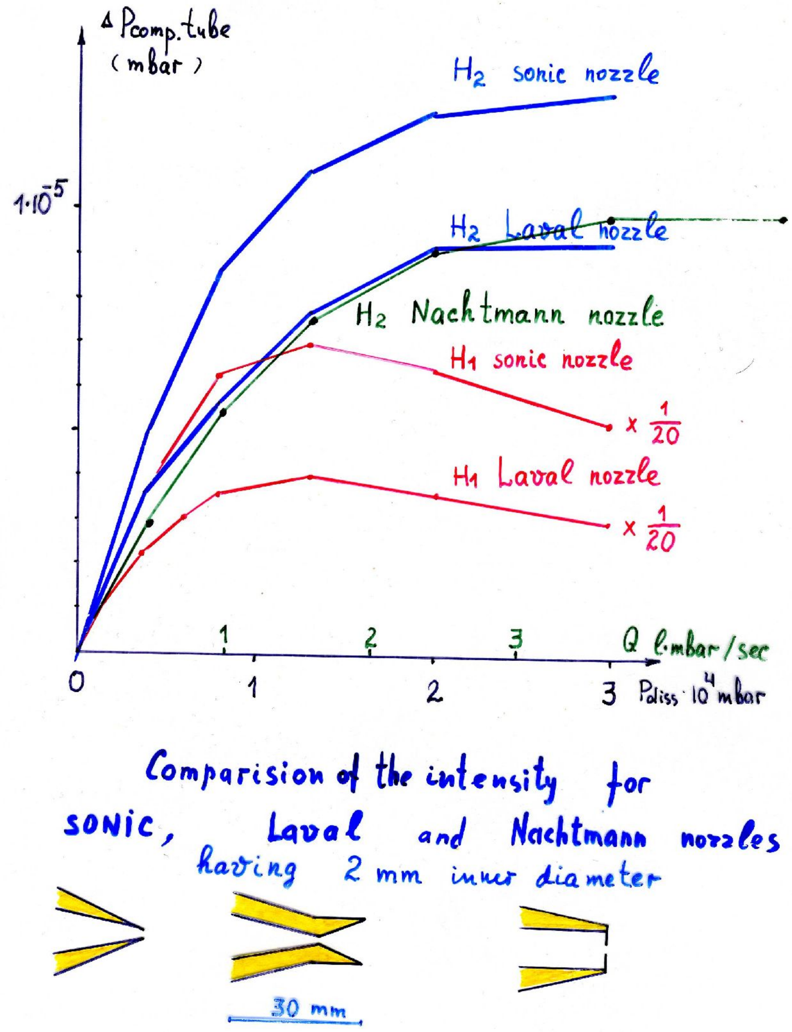


**Test bench measurements. Beam is injected into the compression tube contained QMA. The size of the tube the same as for injection tube of the storage cell**




**RQ=7.32, RI=3.50, RF(I3M/I2M)=(14/10)/(4.8/1.7 – 4.2/1.1) = 0.495 – 0.37**

# FORWARD INTENSITY OF THE BEAM IS DEPENDENT FROM THE GEOMETRY OF THE NOZZLE



## What to measure further to understand the limitation of the atomic beam intensity??

1. Formation of the molecular flow before skimmer
2. Determination position  and dimension of the boundary surface
3. Direct investigation of the intra beam scattering
4. More careful investigation the shape of the nozzle which can provide  more intensity at given position for fixed flow rate
5. Detail investigation of the focusing property of the magnet system versus the magnetic field (current driven magnets)

**Attenuation of the beam by uniform residual gas is well investigated and understood, but we really do not know the pressure_distribution along the beam path.**

**We do not know the shape of the source of atoms, which raise under the expansion of gas through the nozzle.**

**Intra beam scattering is poor investigated experimentally ( only A.Hershcovitch PRL 63(1989)750 has shown that this process totally define the intensity of focused atomic beam at 2K ).**

**Further investigations are required to overcome the limitations and get more density and intensity of polarized atomic beams.**