Technical proposal for upgrade of the present Gas Stripper at the GSI UNILAC

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DOI: 10.1088/1748-0221/20/01/T01013

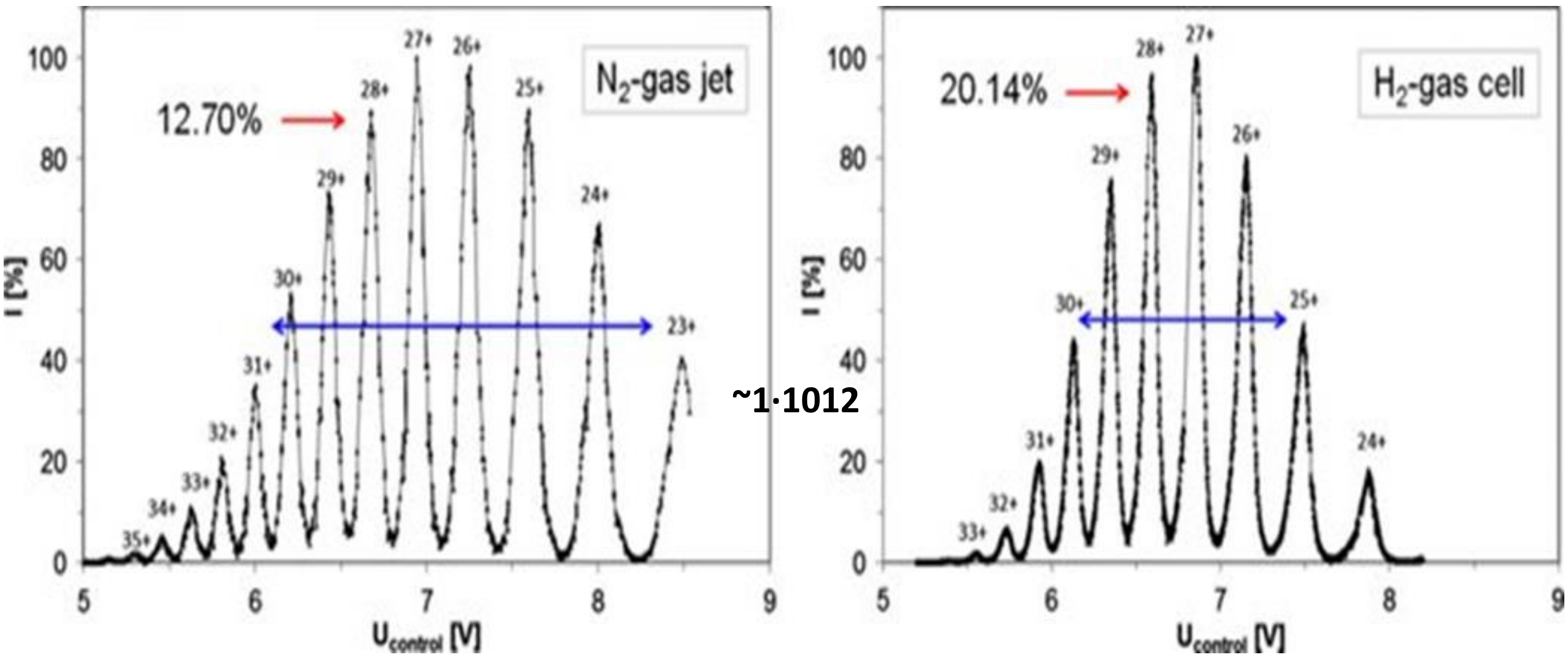
Introduction

Parameters of Strippers at FAIR, FRIB and RIBF

	FAIR /GSI	FRIB /MSU	RIBF /RIKEN
Form	H2 gas Pulsed operation	Liquid Li Film operation	He gas Storage cell
Energy [MeV/u]	1.4	~20	10.8
Input charge	4	33, 34	35
Output charge	28	76, 80	64
Intensity	$\sim 1 \cdot 10^{12}$	$\sim 5 \cdot 10^{13}$	$\sim 1 \cdot 10^{12}$
Thickness [mg/cm2]	~0.03	~0.5	0.7

Present UNILAC gas stripper

Stripped U ion beam charge states spectra



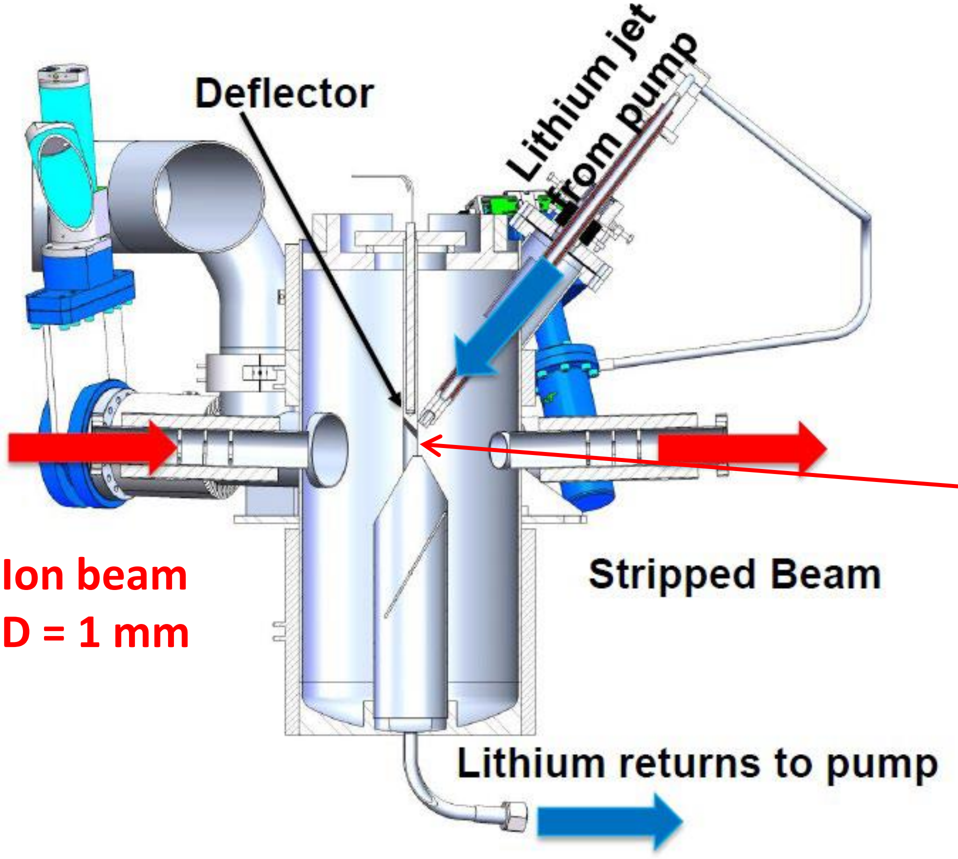
N2-gas jet (left) and H2-pulsed gas stripper cell charge spectra for maximum available target density.

U28^{+}-intensity record applying a H2-gas stripper cell, *Phys. Rev. ST Accel. Beams 18 040101 (2015) 1-9, DOI: 10.1103/PhysRevSTAB.18.040101*

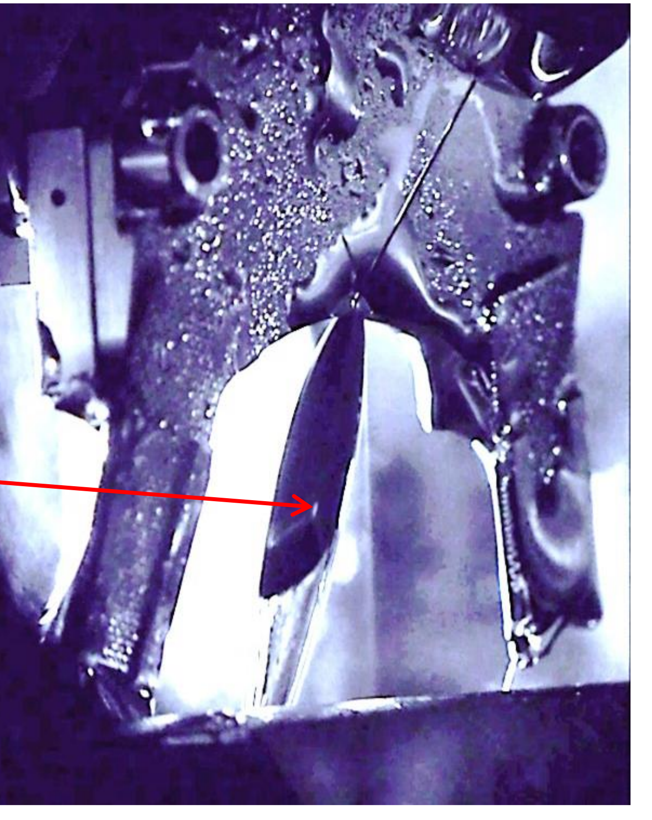
Introduction

LIQUID LITHIUM STRIPPER FOR FRIB

T. Kanemura, et al., Phys. Rev. Lett. 128, 212301 (2022)



Ion beam
D = 1 mm



nozzle D =0.5 mm; Jet flow >50 m/s
P = 10 bar

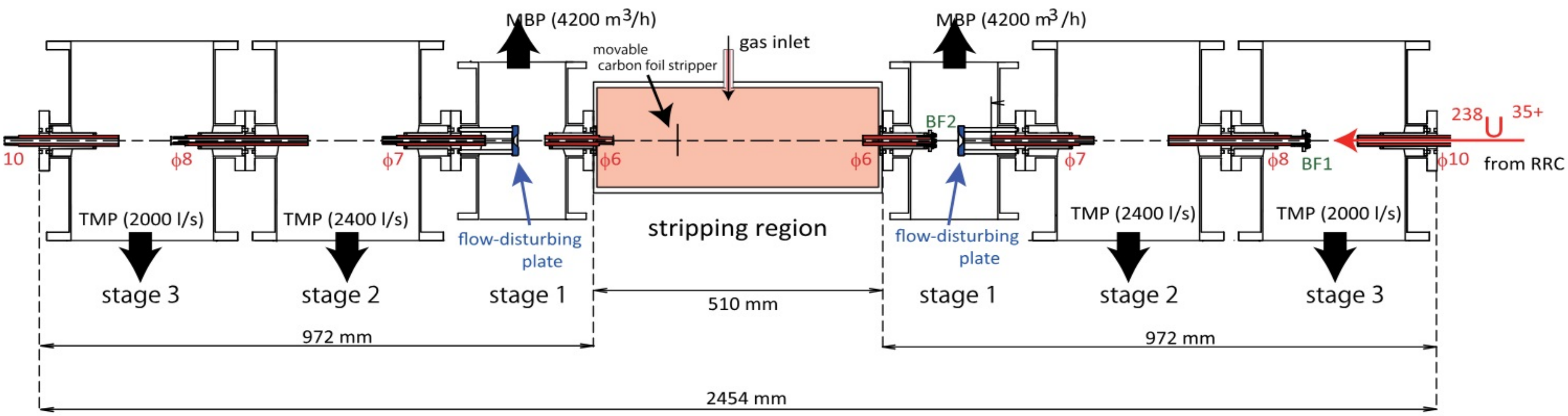
A willow leaf-like liquid lithium film of 10 µm thickness

Introduction

RIKEN storage gas cell stripper

H. Imao, et al., Proc. of IPAC2012 (2012), DOI: 10.1103/PhysRevSTAB.15.12350 .

238U beams injected at 10.8 MeV/u



The system consists of two 5-stage differential pumping systems, one on each side of the 50-cm stripping region.

26 pumps are used in the system

Introduction

RIKEN storage gas cell stripper

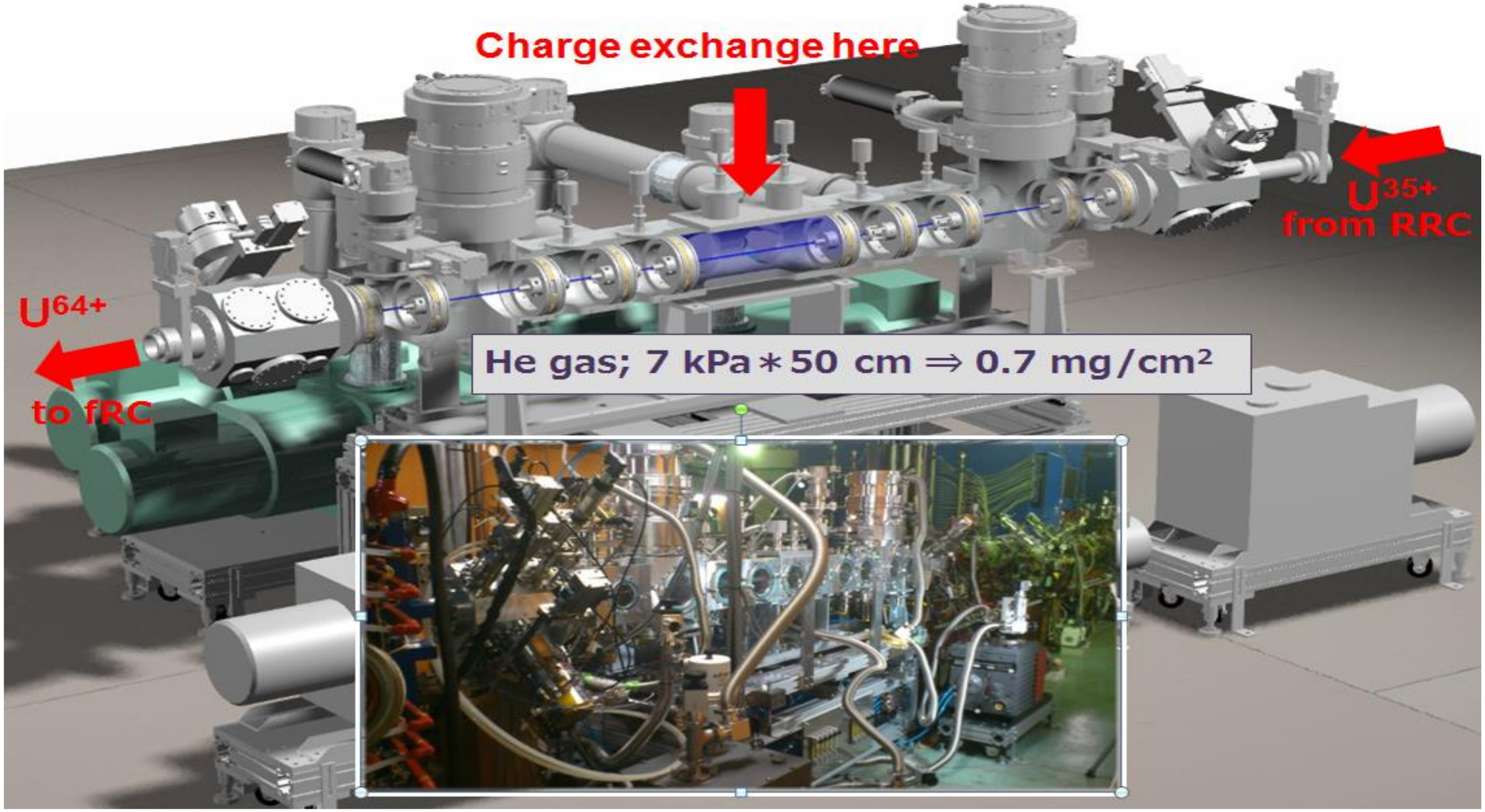
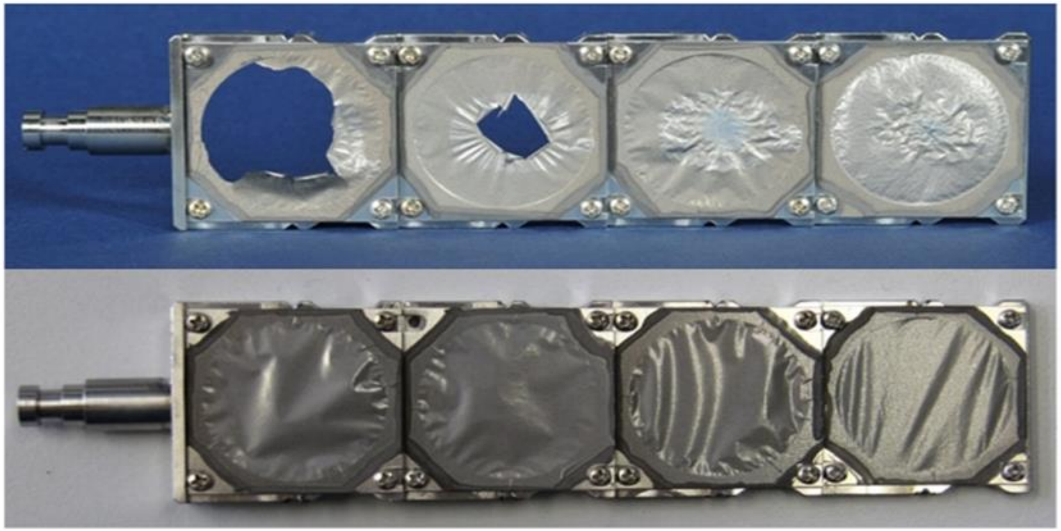


Figure 5: Recirculating He gas stripper at RIBF.

Introduction

Carbon foil stripper for UNILAC high intensity ion beams



Carbon foil stripper before (bottom) and after (top) high current operation.

U28⁺-intensity record applying a H2-gas stripper cell, *Phys. Rev. ST Accel. Beams 18 040101 (2015) 1-9, DOI: 10.1103/PhysRevSTAB.18.040101.*

'It is therefore concluded that the use of a solid stripper foil is not feasible at highest intensities in combination with pulse lengths of 100 µs desired during FAIR operation at the GSI-UNILAC.'

Supersonic gas-jet targets

Gas-jet strippers are a specific type of internal gas-jet targets used in accelerator experiments.

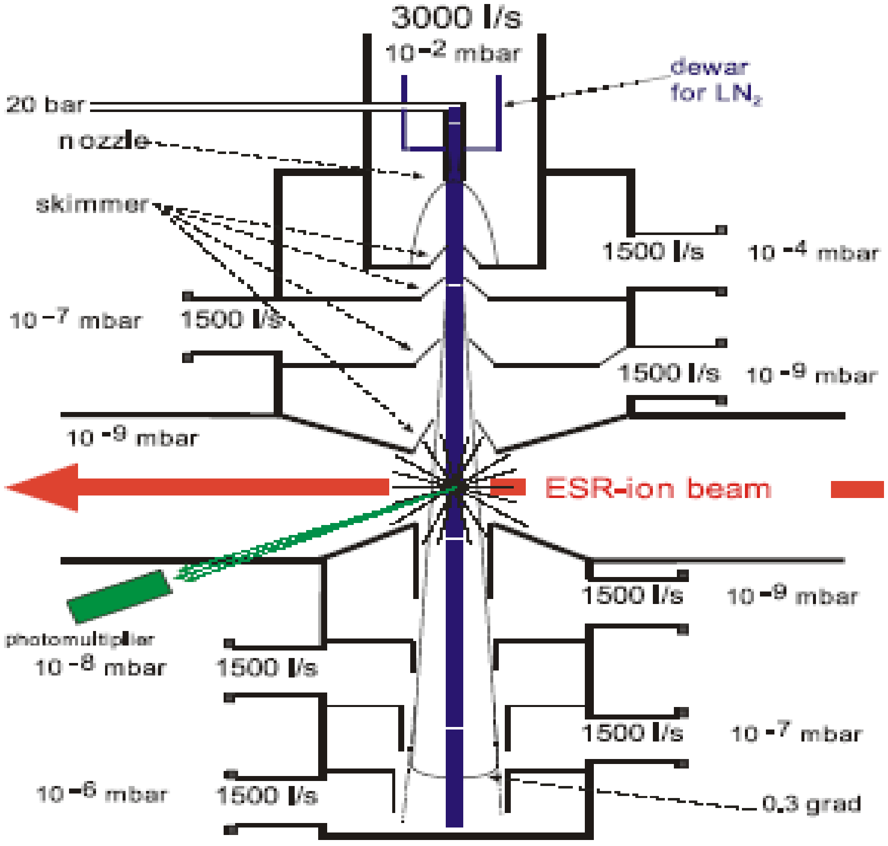
Almost all internal gas-jet targets contain three main elements:

1. **Ion beam**
2. **Supersonic gas-jet**
3. **Gas catcher**

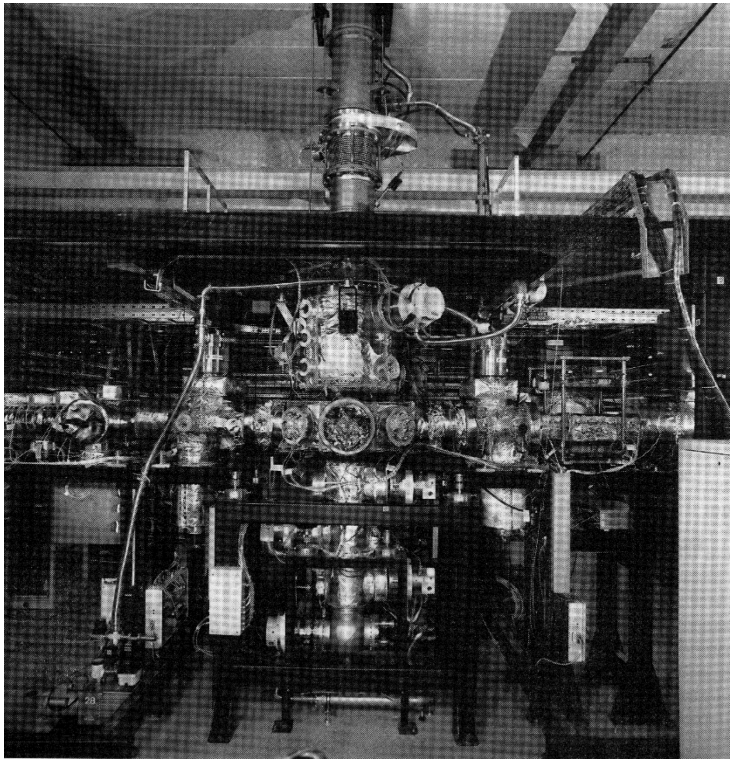
Supersonic gas-jet targets

The ESR internal target at GSI, Darmstadt

H. Reich, W. Bourgeois, B. Franzke, A. Kritzer, V. Varentsov, Nucl. Phys. A 626 (1997) 417



Trumpet-shaped nozzle with 0.1 mm throat diameter



Target densities

He (T= 300 K) – 5*10^{10} p/cm^3

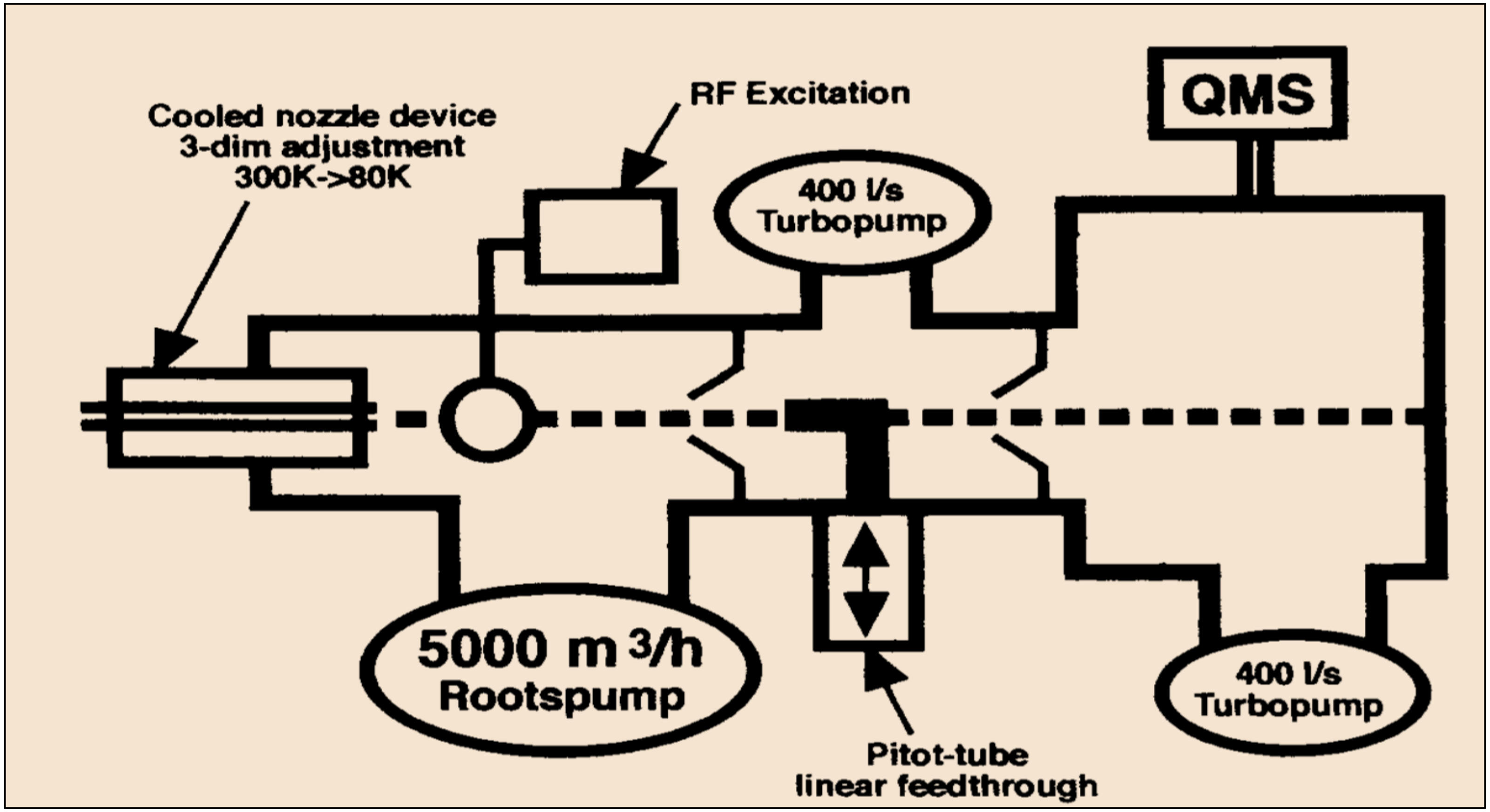
H_2 (T= 300 K) – 3*10^{10} p/cm^3

H_2 (T= 80 K) – 1*10^{13} p/cm^3 - clusters in the jet

Supersonic Jet measurement

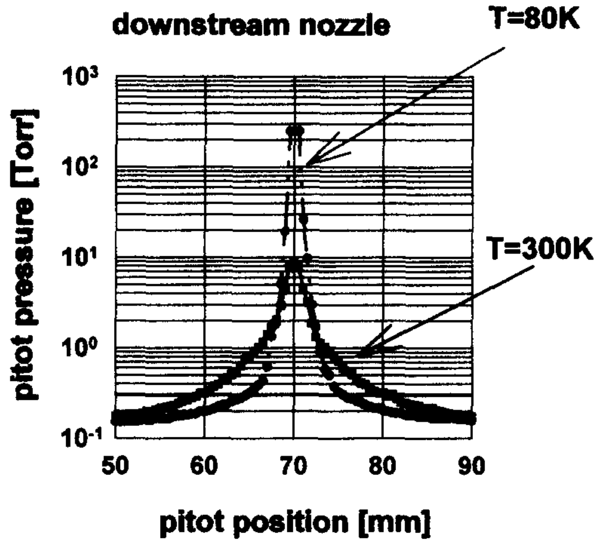
The ESR internal target at GSI, Darmstadt

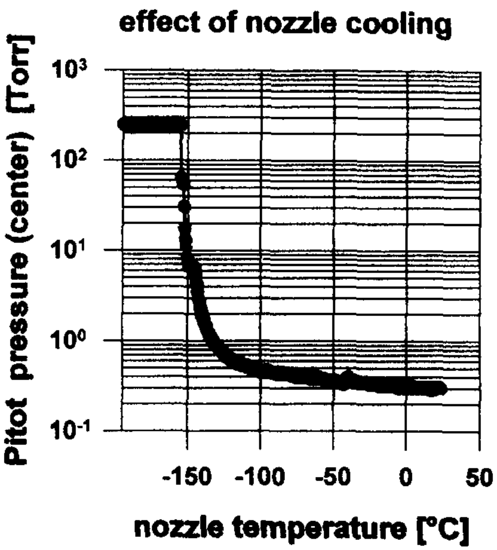
Test stand for ESR internal target

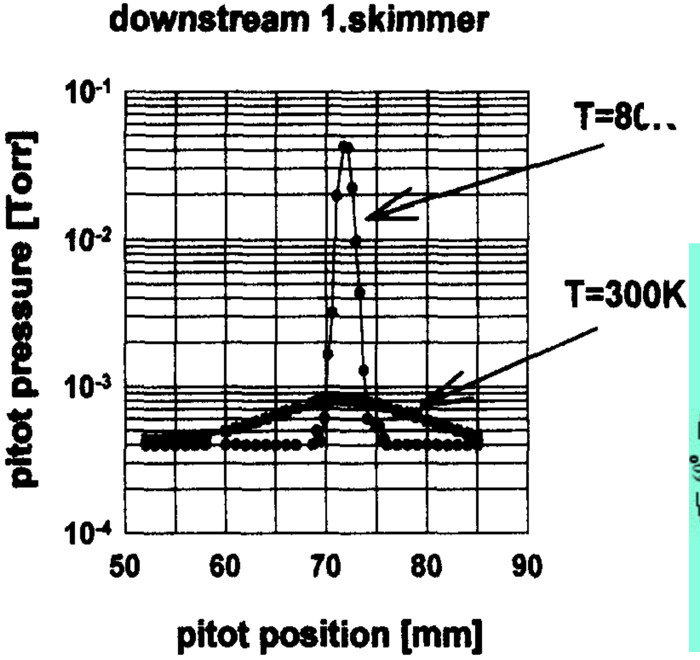


Supersonic Jet measurement

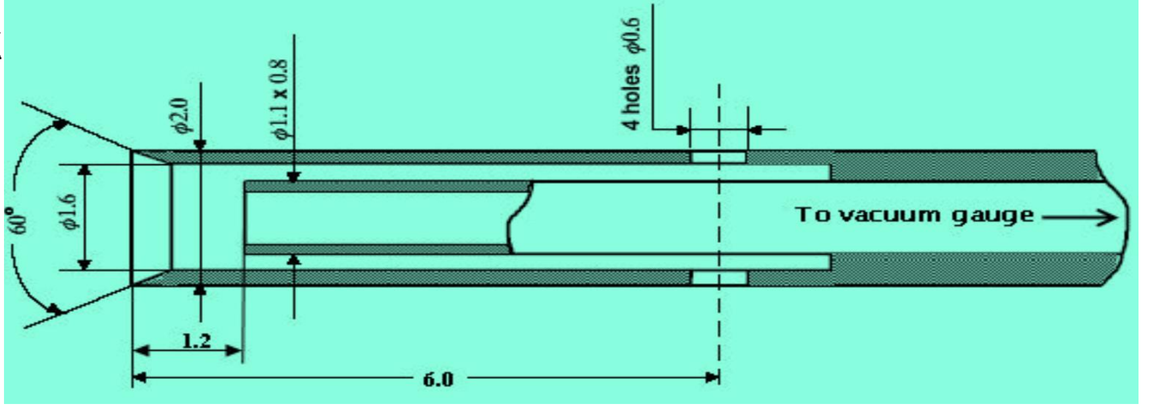
The ESR internal target at GSI, Darmstadt





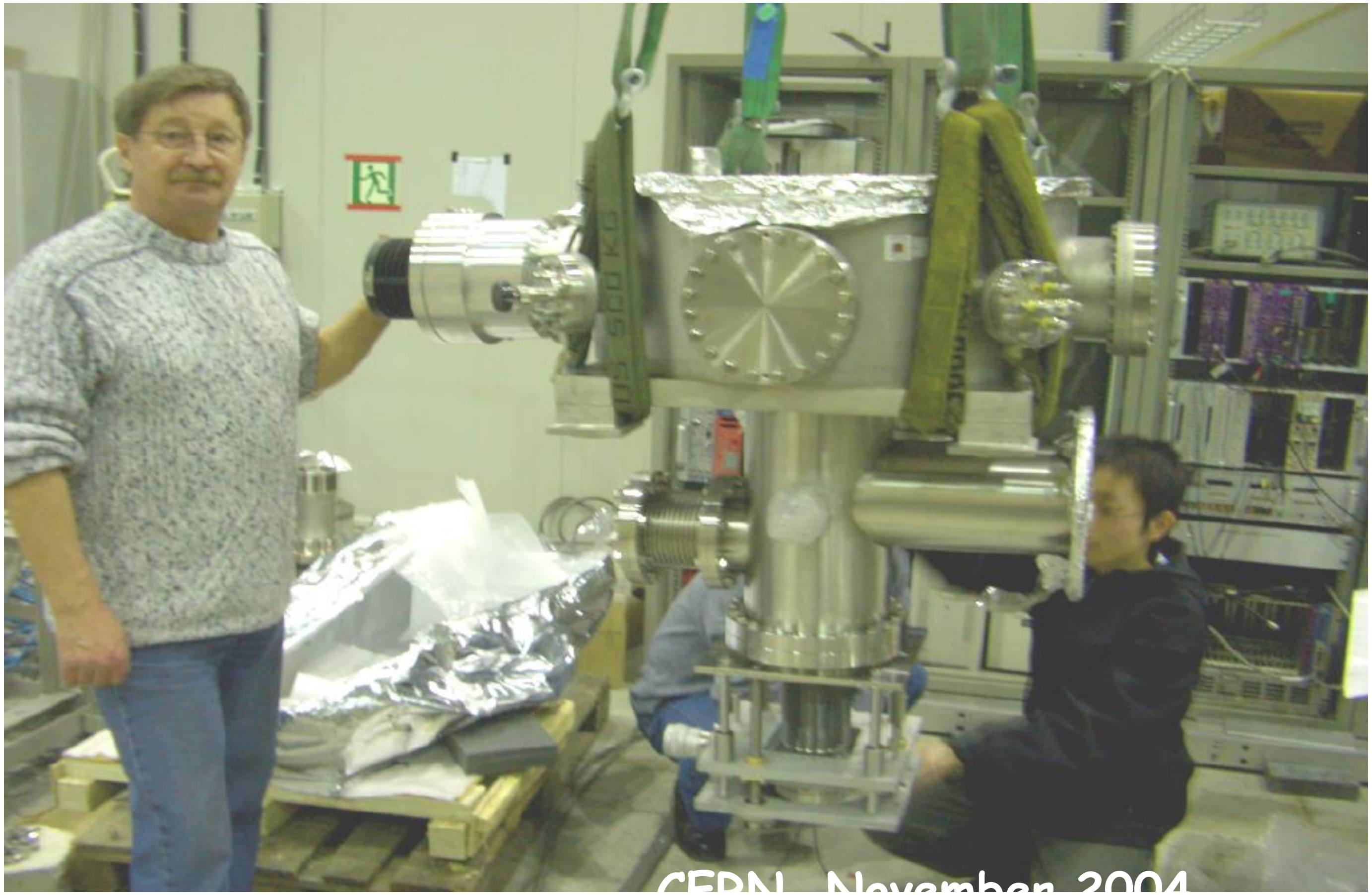


Pitot-tube design



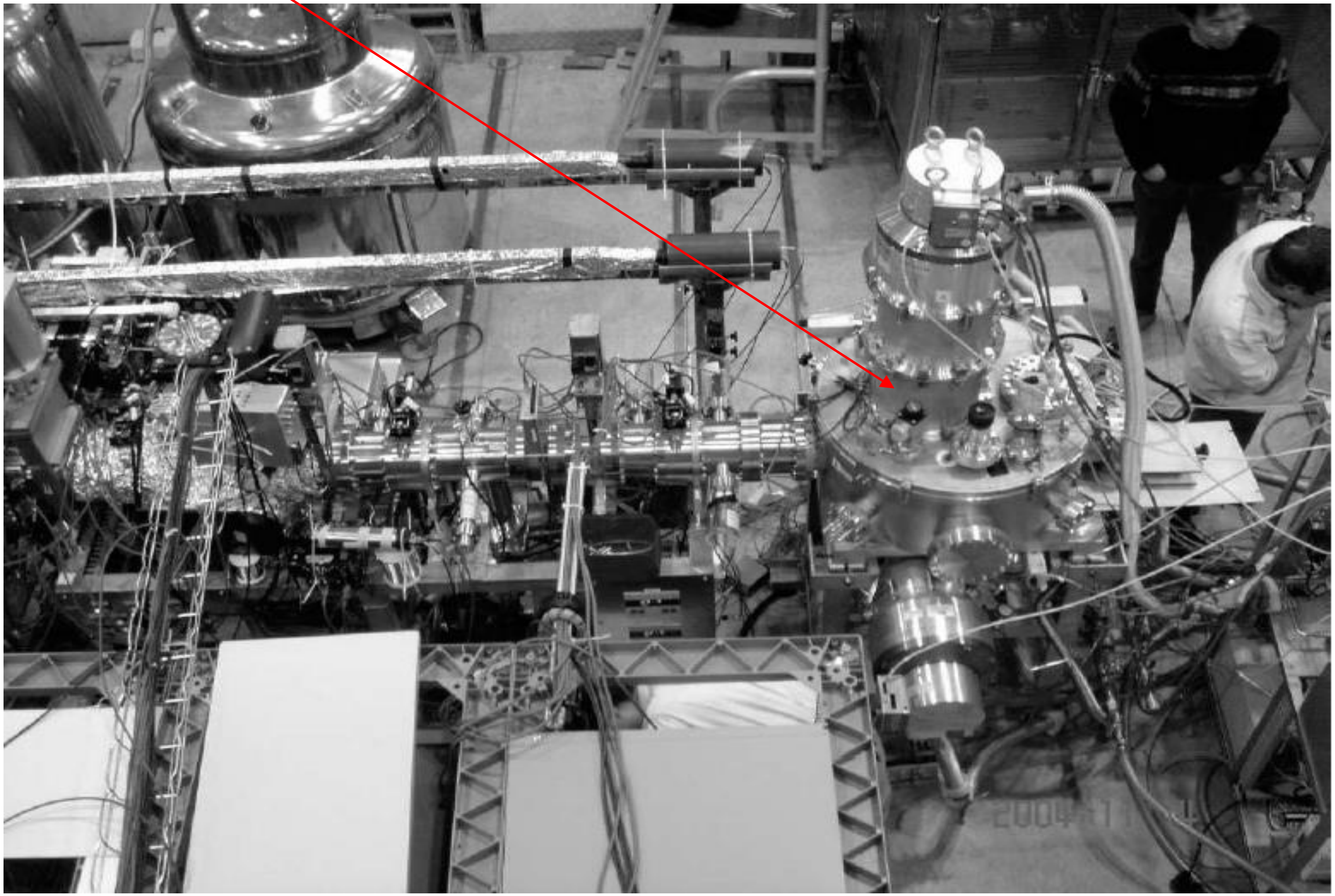
ASACUSA gas-jet target

V. L. Varentsov, N. Kuroda, Y. Nagata, H. A. Torii, M. Shibata, and Y. Yamazaki, [ASACUSA Gas-Jet Target: Present Status And Future Development], AIP Conference Proceedings 793, 328 (2005);
https://doi.org/10.1063/1.2121994



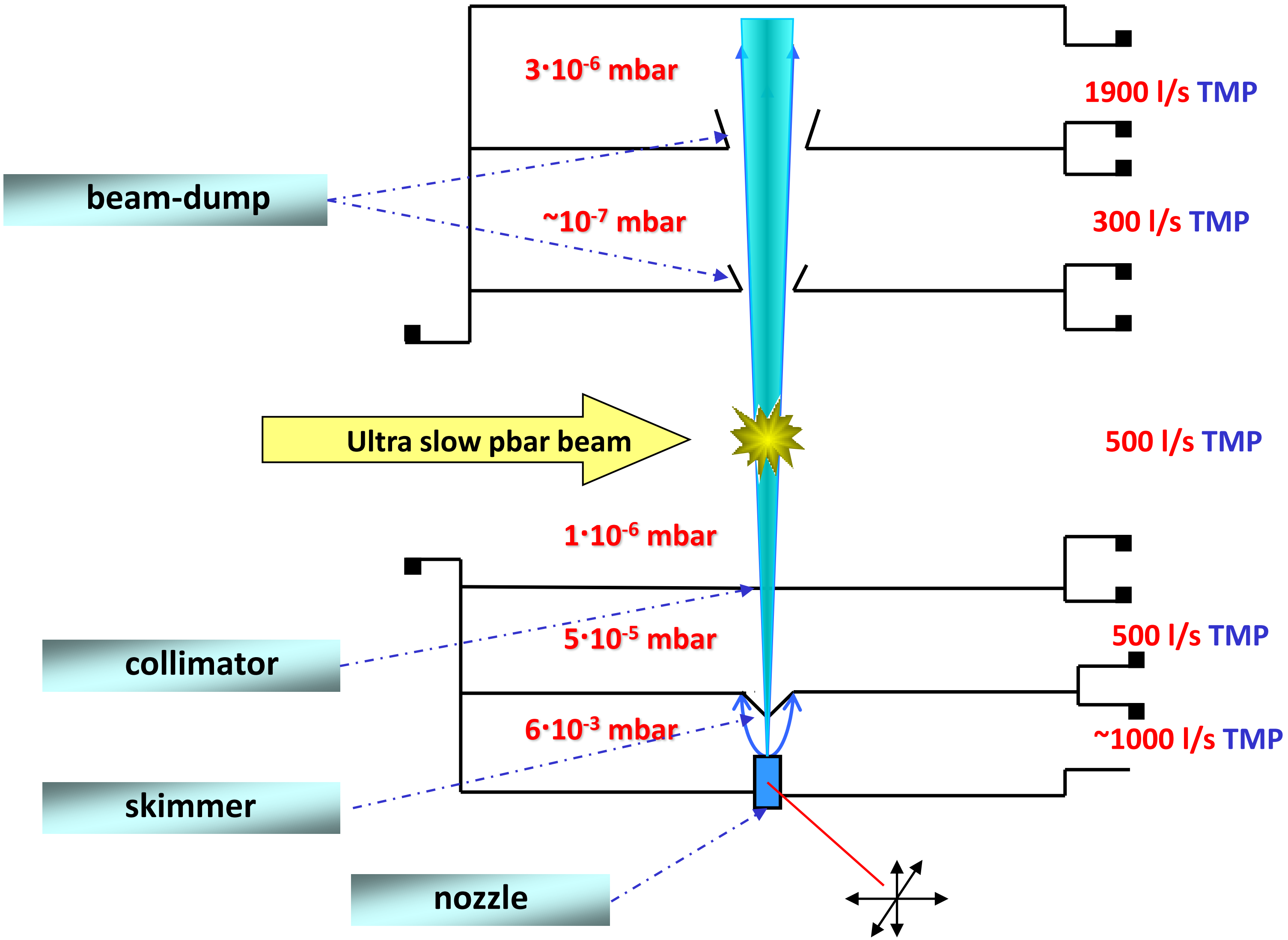
ASACUSA gas-jet target

Gas-jet target setup connected to the MUSASHI beamline



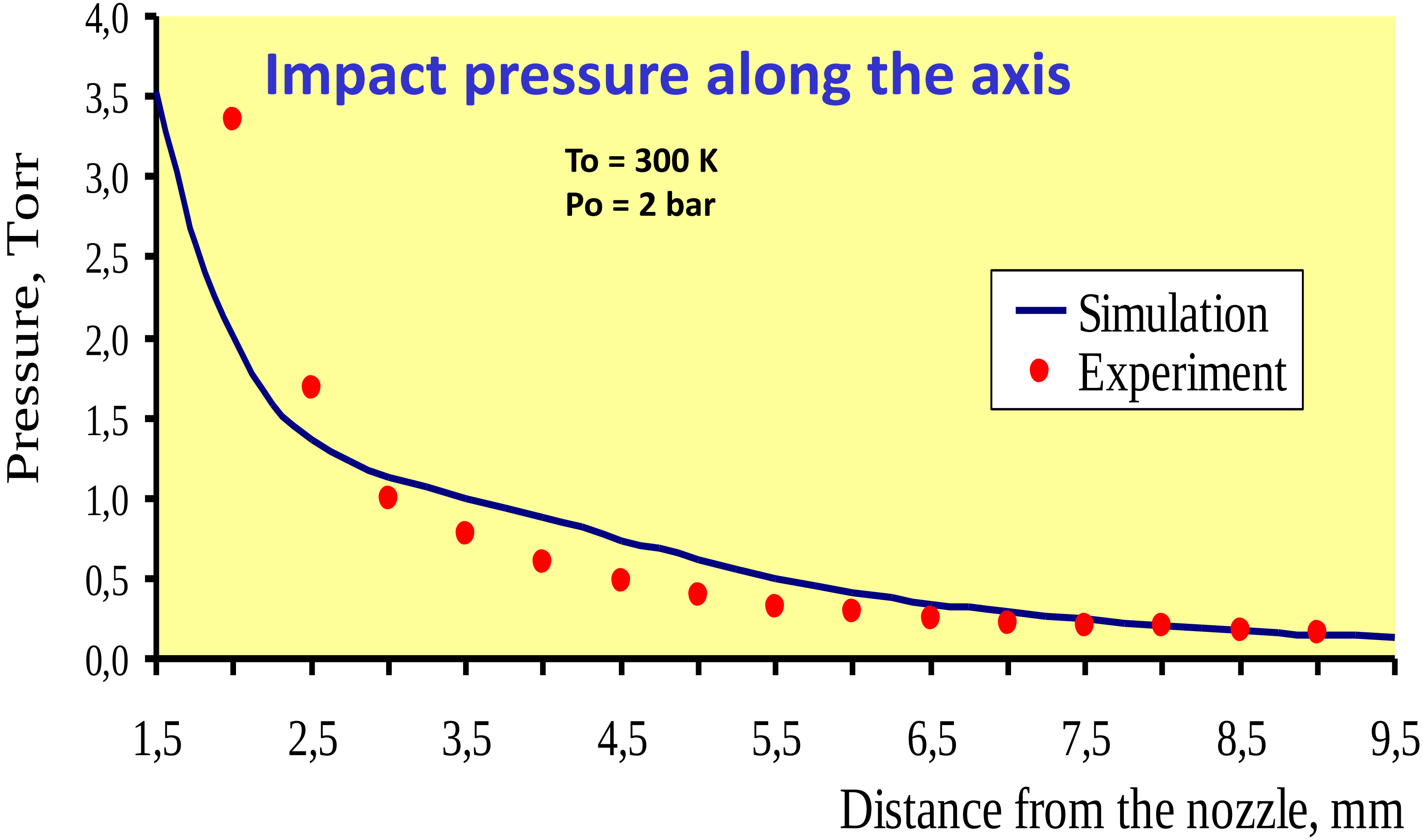
ASACUSA gas-jet target

Schematic figure of the gas-jet target



Supersonic Jet measurement and simulation

ASACUSA gas-jet target, CERN 2004



Supersonic gas-jet targets

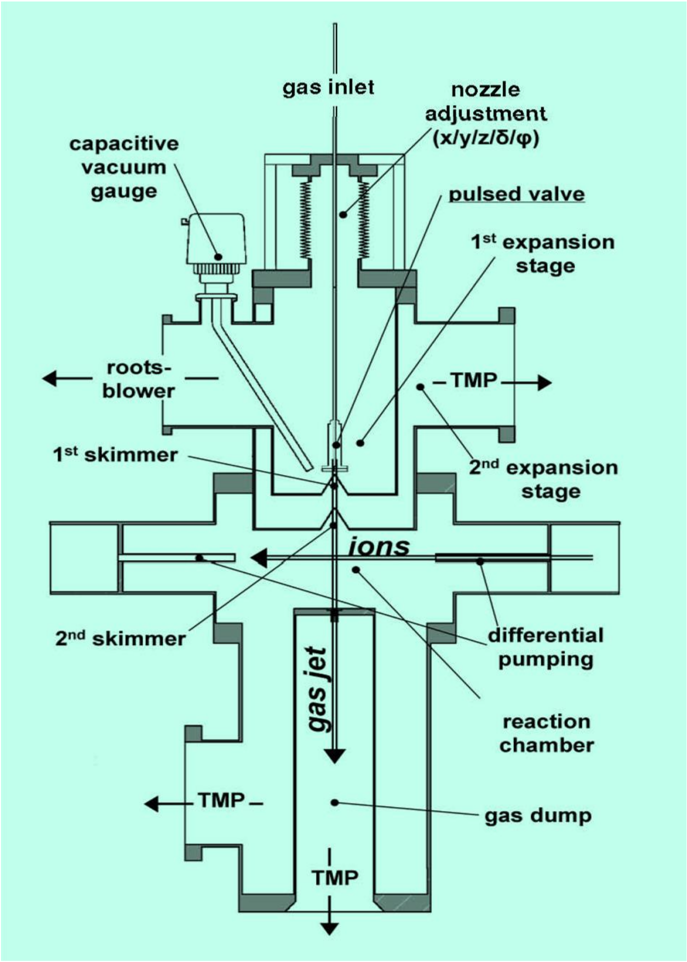
A pulsed gas jet target for the HITRAP facility at GSI

D. Tiedemann, K.E. Stiebing, D.F.A. Winters, W. Quint, V. Varentsov, A. Warczak, A. Malarz, Th. Stöhlker, A pulsed supersonic gas jet target for precision spectroscopy at the HITRAP facility at GSI, Nuclear Instruments and Methods in Physics Research Section A, 764 (2014) 383, https://doi.org/10.1016/j.nima.2014.08.017.

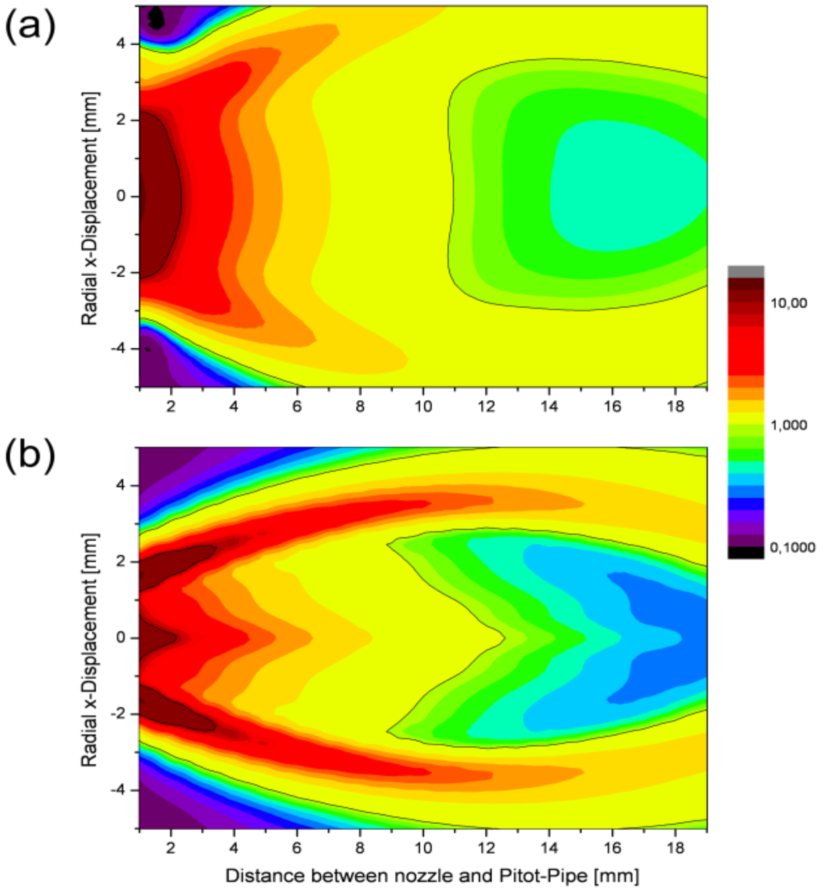
Presently installed in the Low-energy Storage Ring (FLSR), Goethe University, Frankfurt

Supersonic gas-jet targets

A pulsed gas jet target for the HITRAP facility at GSI



Schematic view of the supersonic gas-jet target for HITRAP.

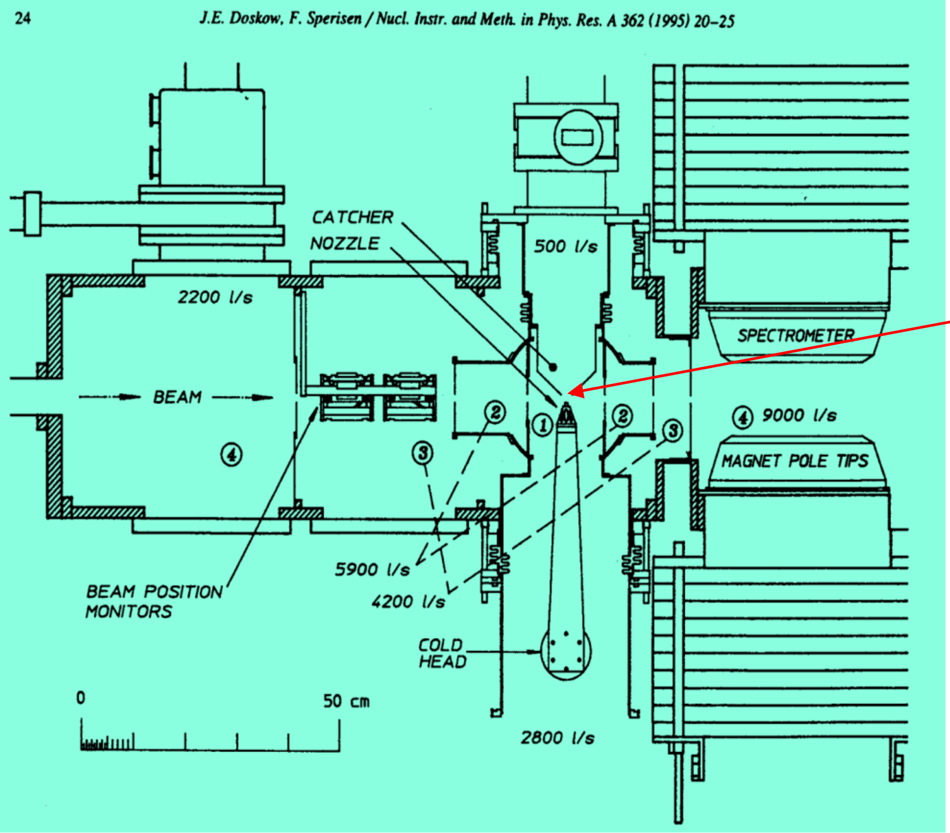


The impact pressure flow field of the supersonic gas jet (a) in comparison with simulation results (b).

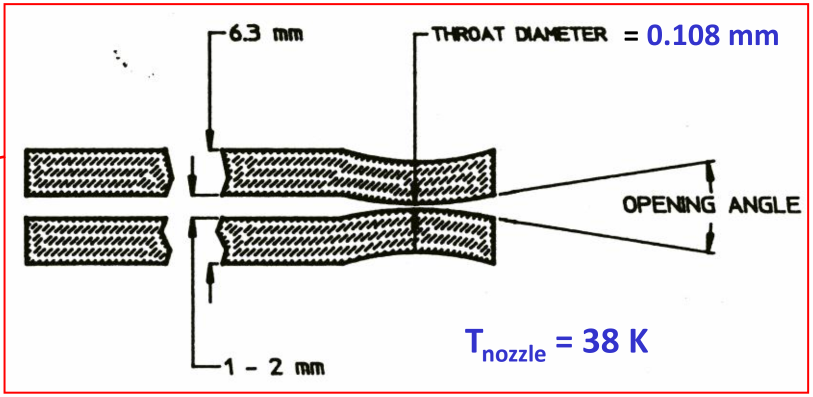
Supersonic gas-jet targets

Indiana Cooler ring target at IUCF, Bloomington

J.E. Doskov, F. Sperisen, Nucl. Instr. and Meth., A362 (1995) 20



Geometry of glass nozzle



H_2 flow rate through the nozzle = $1*10^{20}$ mol./s

~ 4 mbar l/s

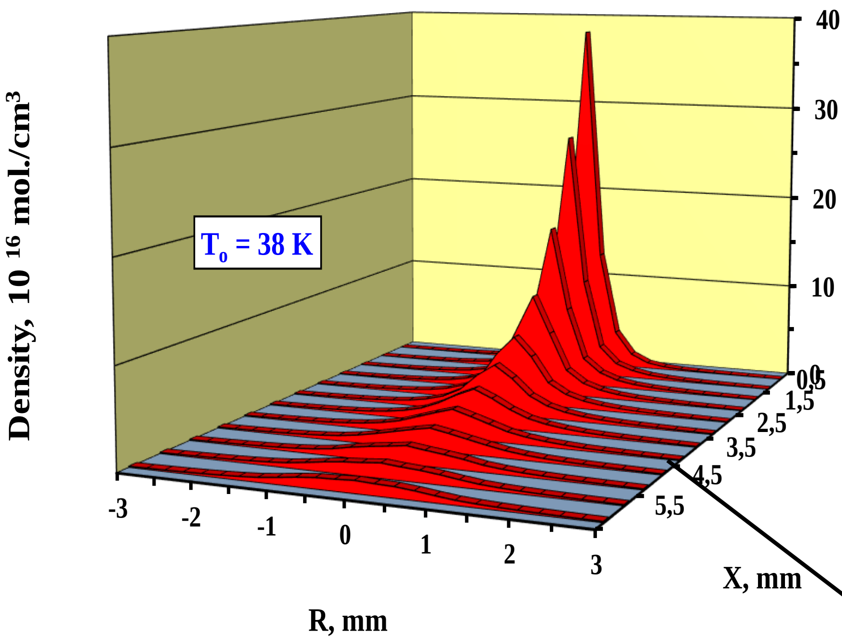
Background pressure in the scattering chamber > $5*10^{-4}$ mbar

Nozzle – gas-catcher distance = 14 mm

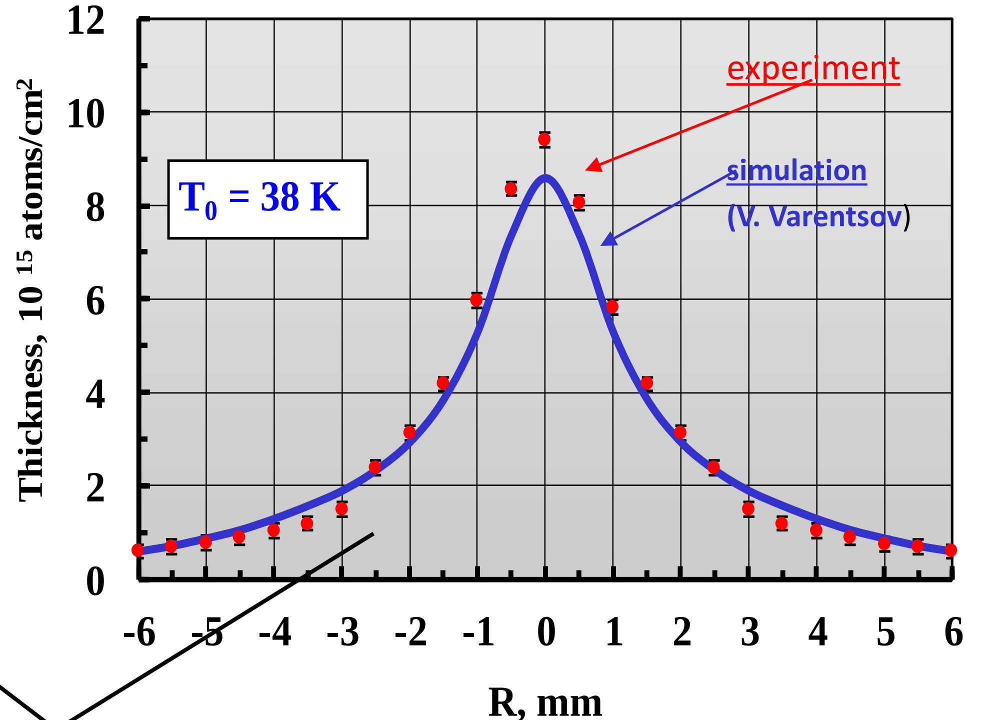
Supersonic Jet measurement and simulation

Indiana Cooler ring target at IUCF, Bloomington

Computed density profile of H_2 supersonic jet (V. Varentsov)



Hydrogen target thickness profile at 5 mm downstream the nozzle exit



Simulation:

see V.L. Varentsov and A.A. Ignatiev, Nucl. Instr. and Meth., A413 (1998) 447

Supersonic gas-jet targets

JENSA gas jet Target at the ORNL, USA

K.A. Chipps et al., The Jet Experiments in Nuclear Structure and Astrophysics (JENSA) gas jet target,
Nucl. Instr. and Meth., A763 (2014) 553 -564.

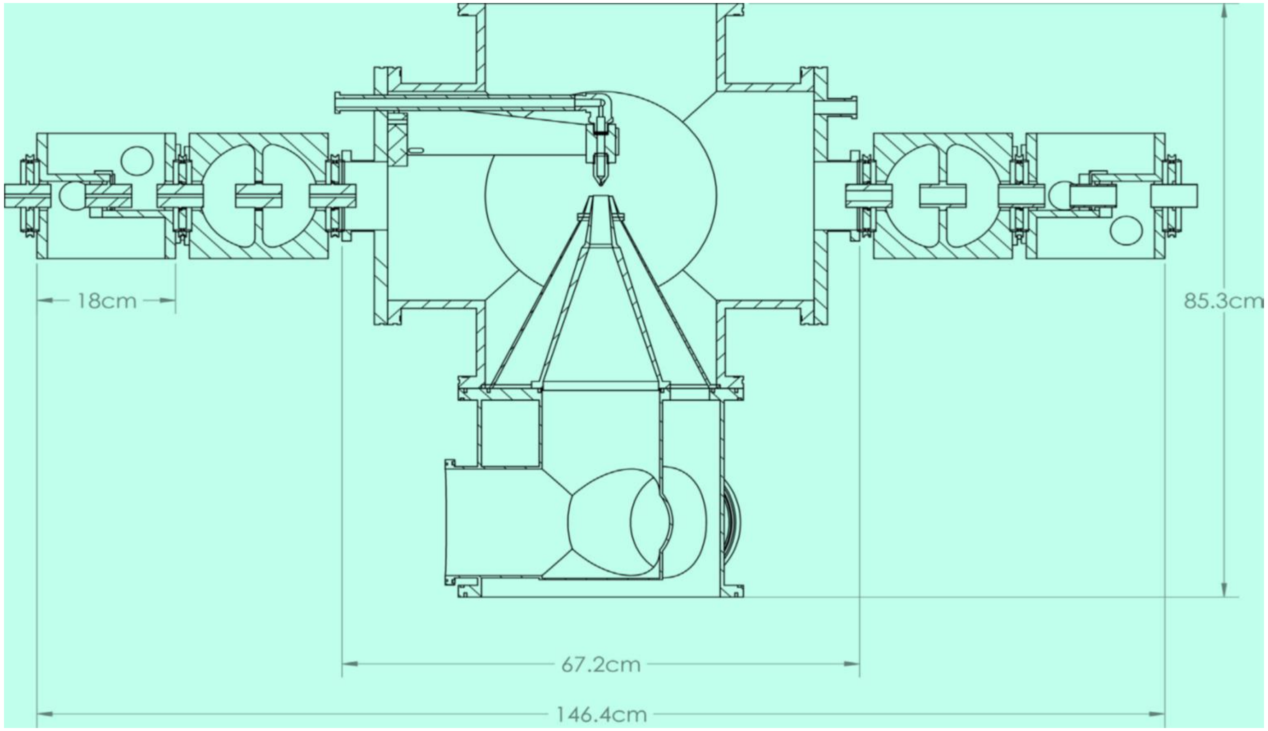


Fig. 1. CAD schematic of the central chamber and differential pumping stages of the JENSA gas jet target.

Supersonic gas-jet targets

JENSA gas jet Target at the ORNL, USA

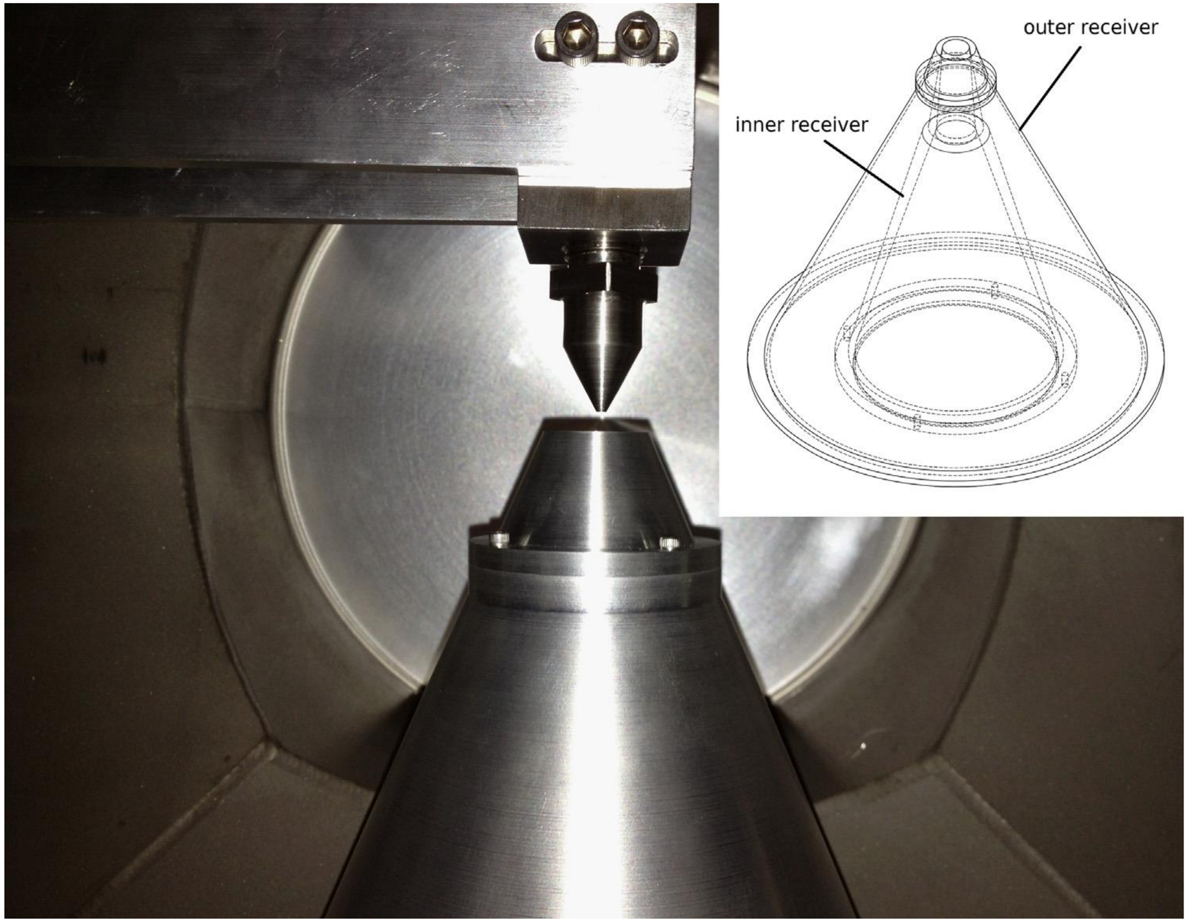


Fig. 4. Photograph of the inside of the JENSA central chamber, showing the orientation of the Laval nozzle (jet-producing) and receivers (gas-catching).

Supersonic gas-jet targets

HIPPO gas-jet target at the University of Notre Dame, USA

Zach Meiselm Ke Shi, Aleksandar Jemcov , Manoel Couder, Exploratory investigation of the HIPPO gas-jet target fluid dynamic properties,
Nucl. Instr. and Meth., A828 (2016) 8 -14.

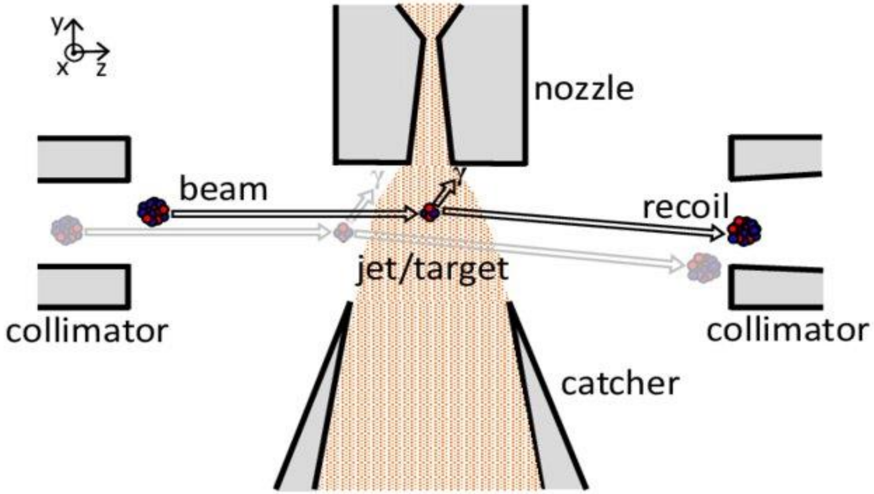
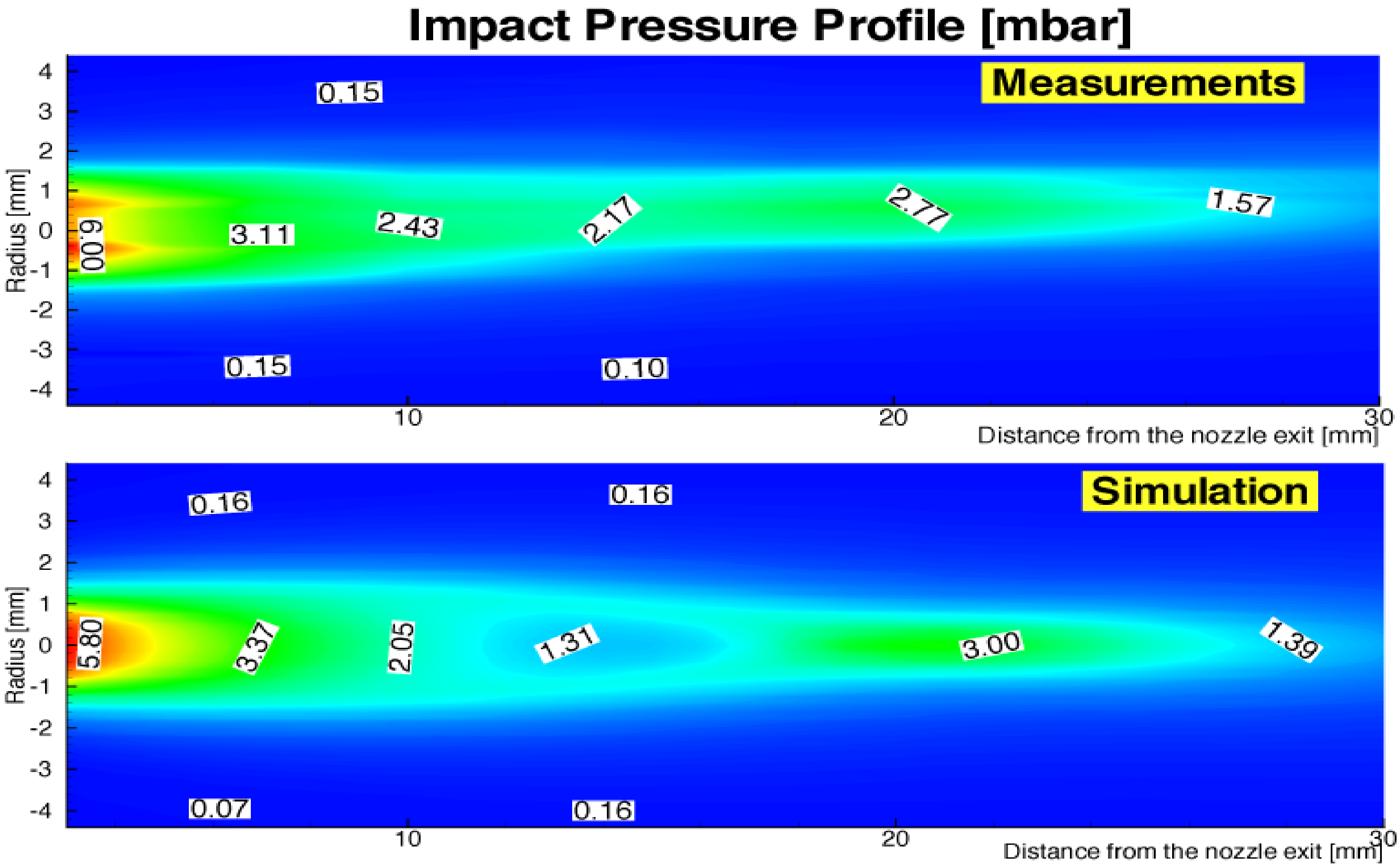


Figure 1: (color online.) Schematic of the HIPPO gas-jet target, viewed perpendicular to the ion beam and gas-jet axes.

Supersonic Jet measurement and simulation

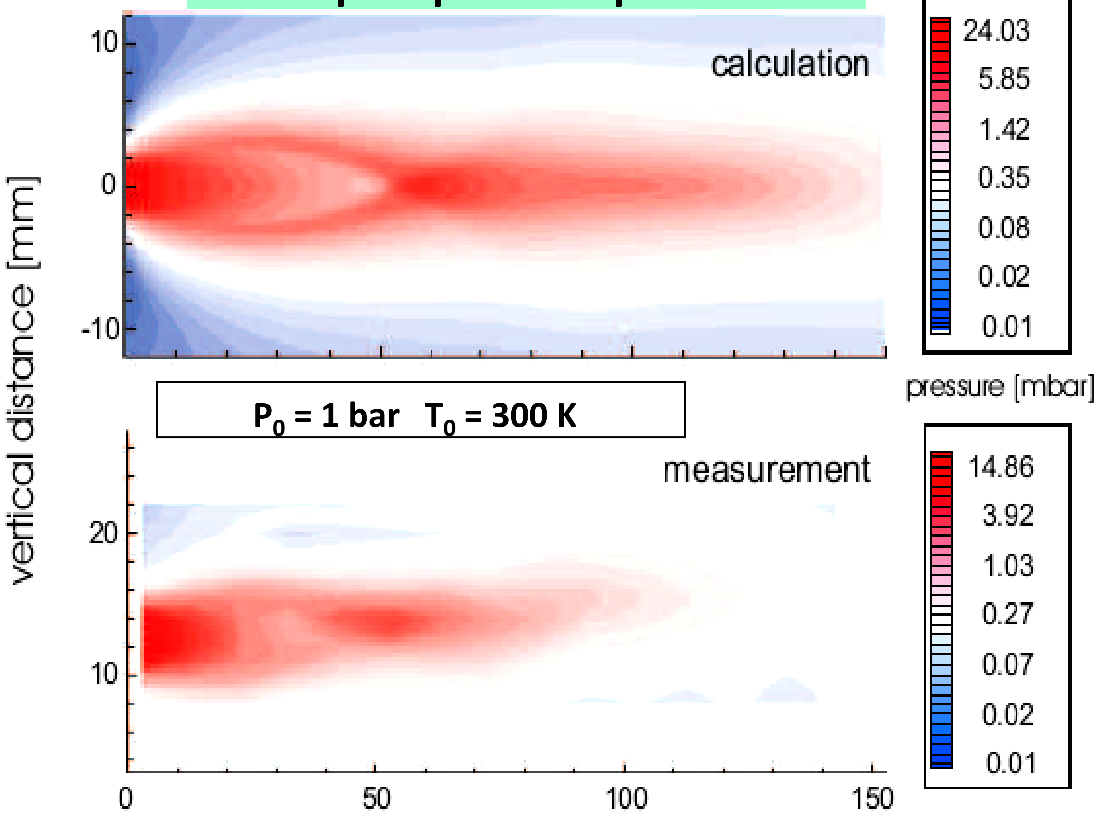
Supersonic jet from the nozzle of SHIPTRAP stopping gas cell, Munich University, 2000



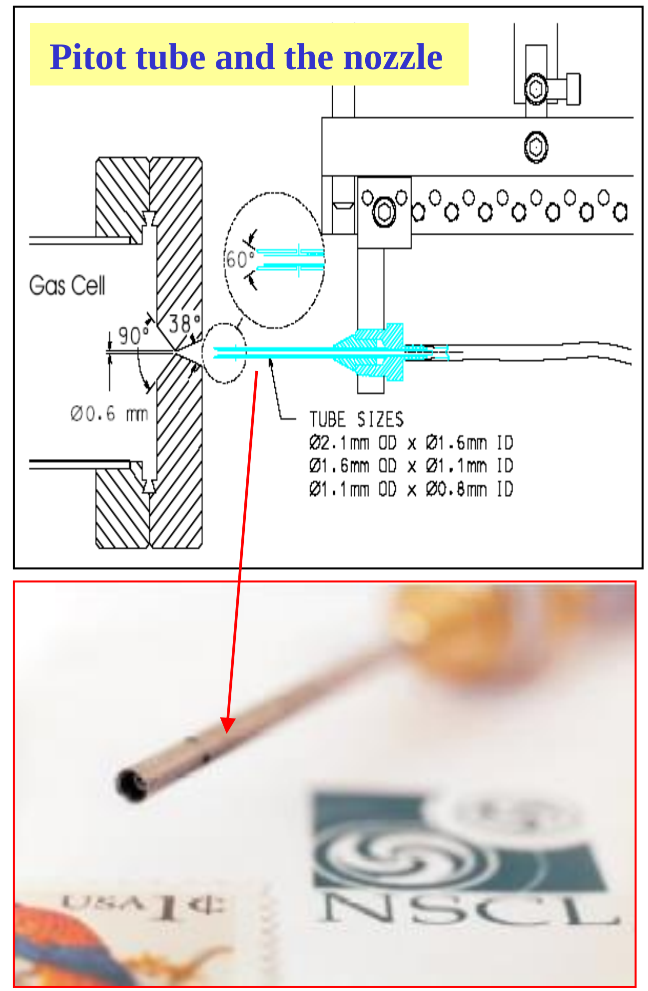
Supersonic Jet measurement and simulation

He supersonic jet from a conical converging-diverging nozzle of NSCL stopping gas cell, Michigan State University, 2001

Impact pressure profile



Distance from the nozzle, mm



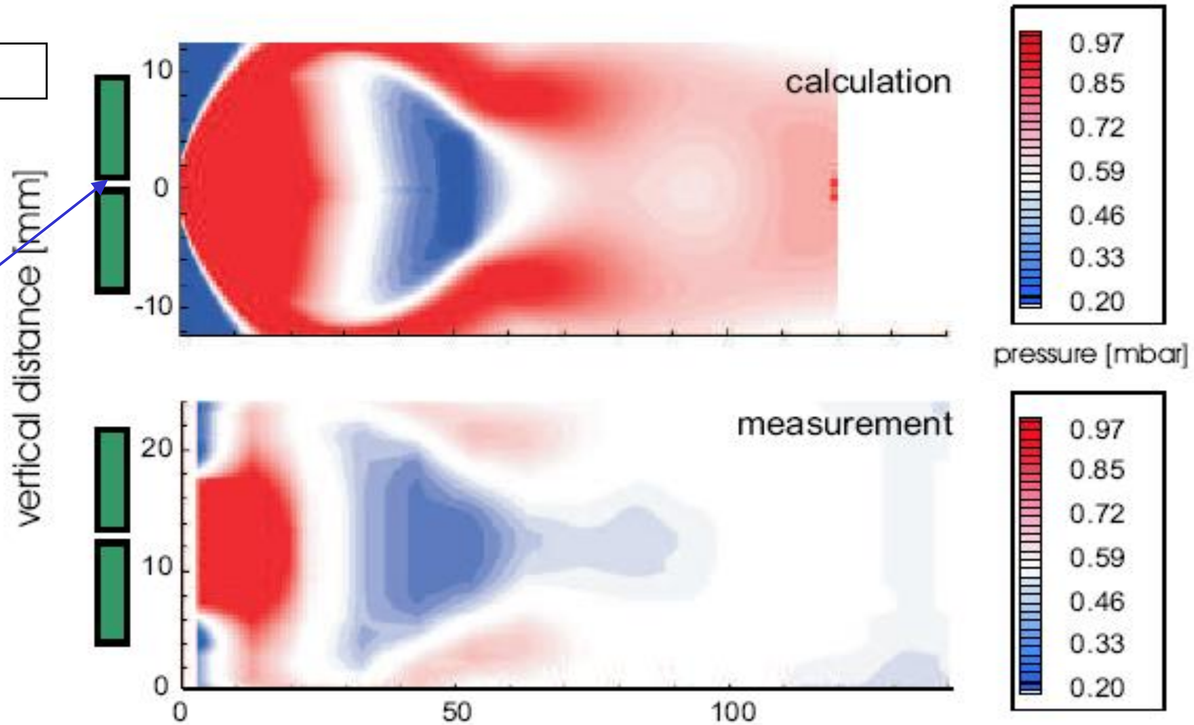
Supersonic Jet measurement and simulation

He supersonic jet from a cylindrical nozzle of NSCL stopping gas cell, Michigan State University, 2001

Impact pressure profile

P_0 = 1 bar T_0 = 300 K

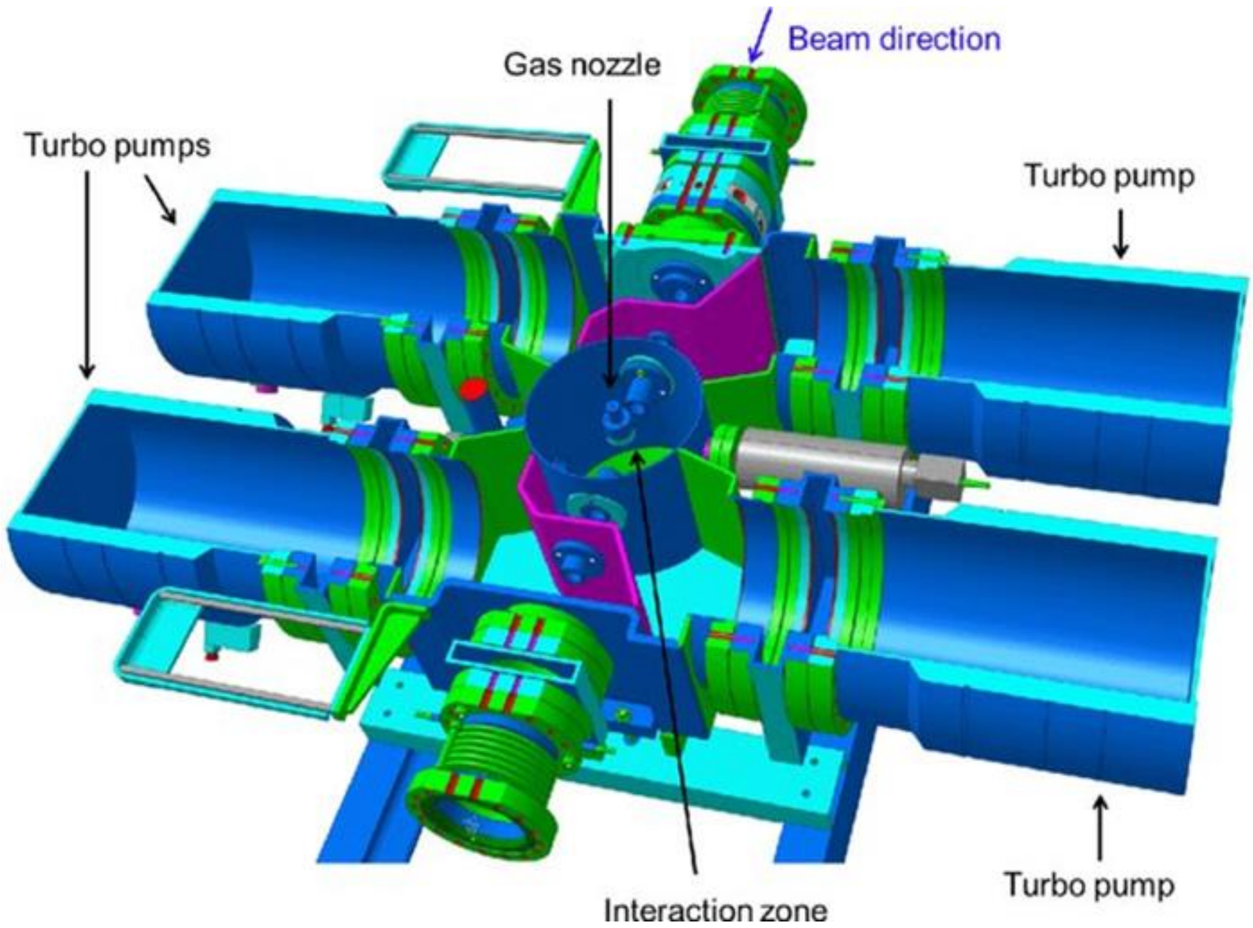
Nozzle diameter = 1 mm



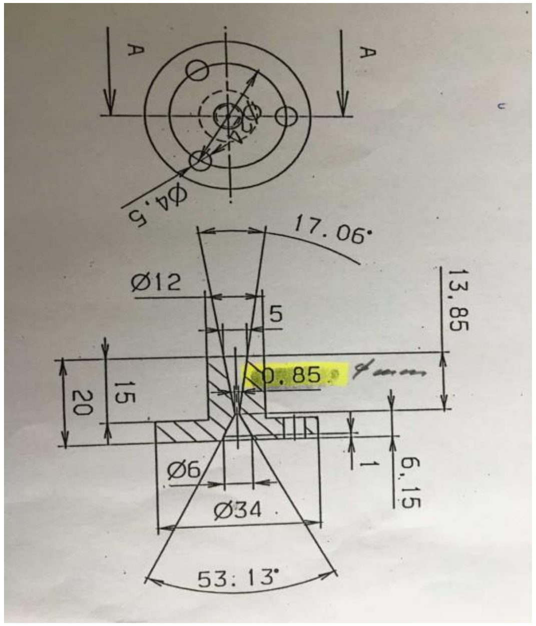
Distance from the nozzle, mm

Present UNILAC gas stripper

Continuous supersonic jet operation



Conical Nozzle geometry	
Throat diameter	0.85 mm
Exit diameter	5.0 mm
Length	13.85 mm

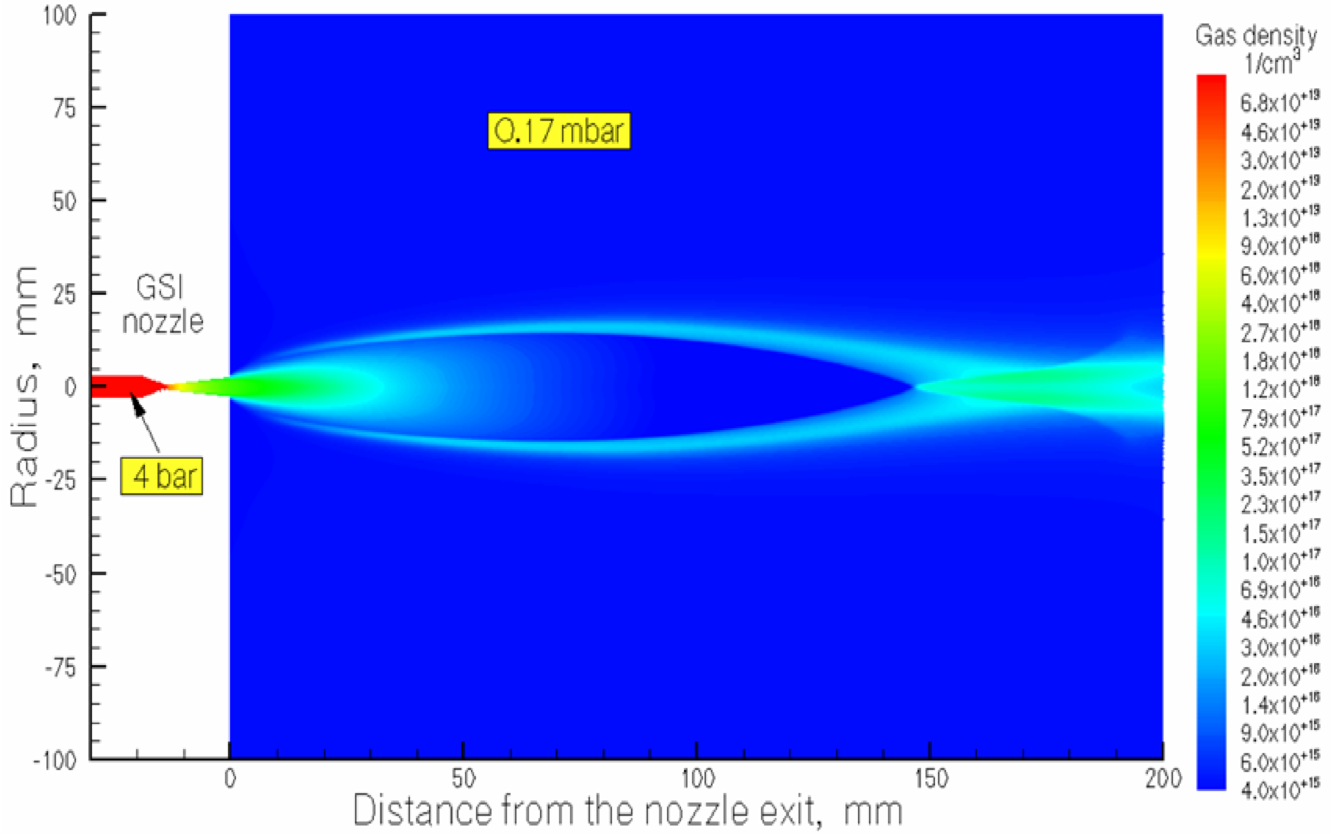


The 3D schematic of the gas stripper box. It is a copy of the Figure 2 from the GSI article:
U28⁺-intensity record applying a H2-gas stripper cell, *Phys. Rev. ST Accel. Beams 18 040101 (2015) 1-9, DOI: 10.1103/PhysRevSTAB.18.040101.*

Present UNILAC gas stripper

Continuous nitrogen supersonic jet operation

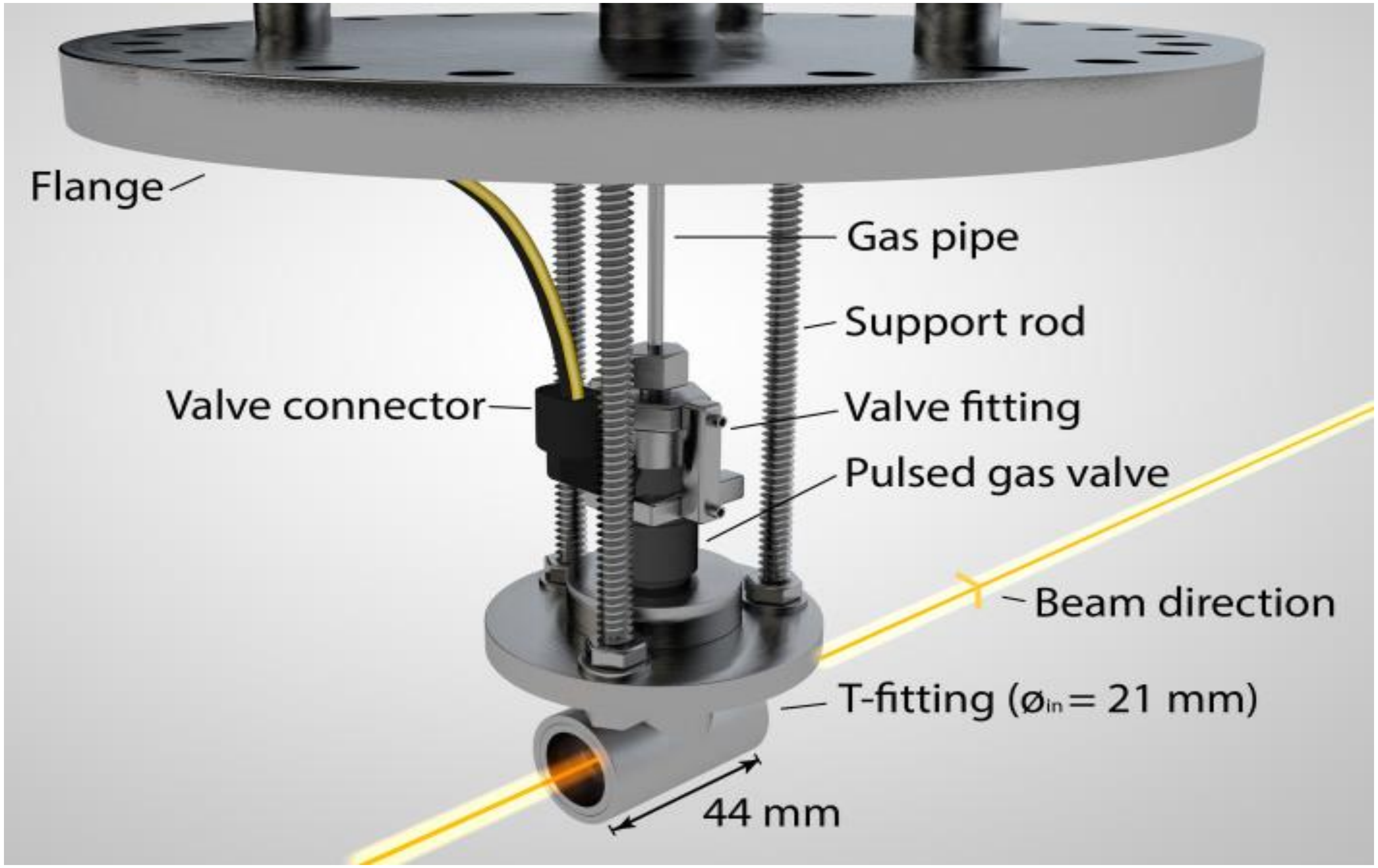
Due to the vacuum limitation (?) **it can be used in the UNILAC gas stripper only for** ***stagnation nitrogen gas pressures up to 4.5 bar***



The result of our simulation of the nitrogen density flow field for the present GSI nozzle. The calculated background pressure in the main stripper chamber is P_{bg} = 0.17 mbar for nominal Roots pumping speed of 2222 l/s.

Present UNILAC gas stripper

Pulsed gas stripper operation mode

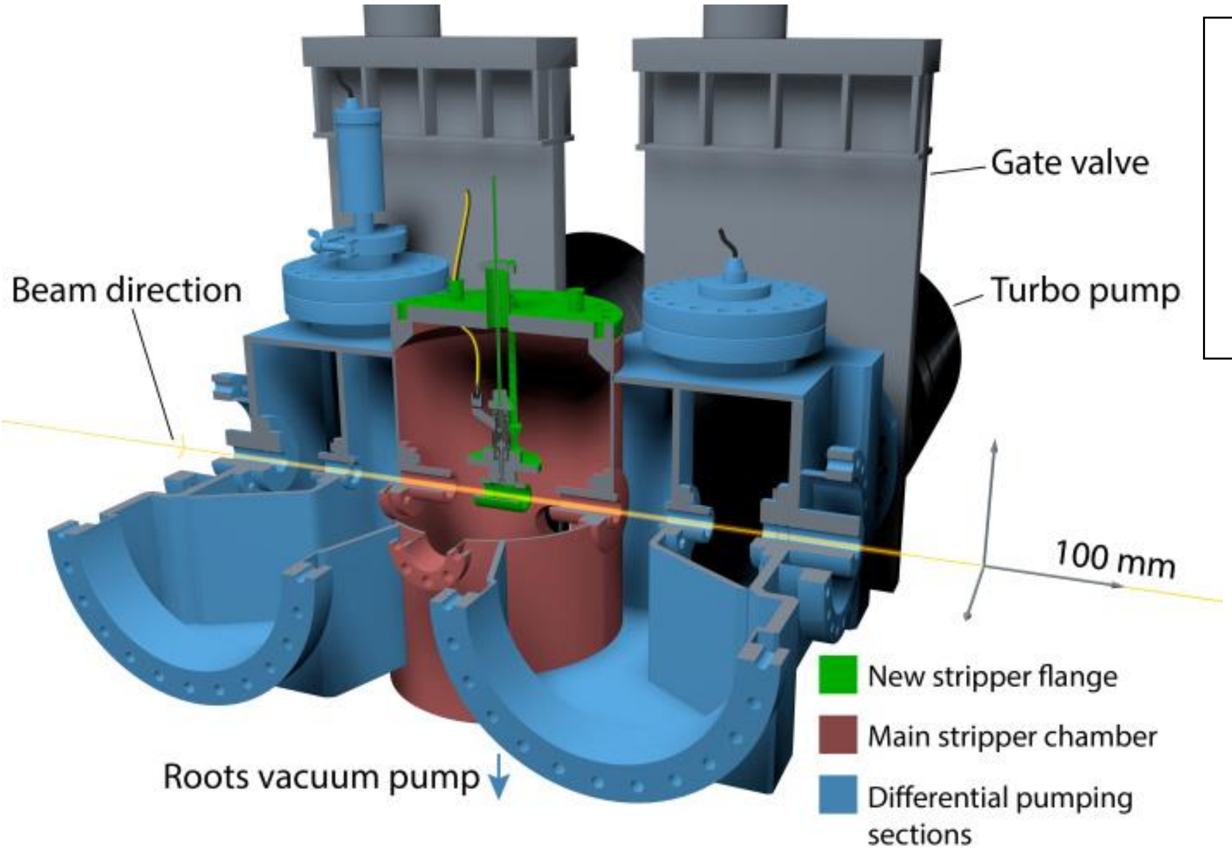


Ion beam diameter is 20 mm

The 3D model of the pulsed gas stripper equipment assembled on the top flange of the main stripper chamber. It is a copy of the Figure 2 from the GSI article: Stripping of high intensity heavy-ion beams in a pulsed gas stripper device at 1.4MeV/u, *Proceedings of IPAC2015, Richmond, VA, USA (2015) 3773-3775.*

Present UNILAC gas stripper

Pulsed gas stripper operation mode



Main chamber – Roots pump of 2222 l/s (nominal)

4 subsidiary chambers – Turbo pump of 1200 l/s each (nominal)

The 3D schematic of the gas stripper box with the pulsed gas stripper equipment. It is a copy of the Figure 1 from the GSI article: Stripping of high intensity heavy-ion beams in a pulsed gas stripper device at 1.4MeV/u, *Proceedings of IPAC2015, Richmond, VA, USA (2015) 3773-3775.*

Proposal for UNILAC gas stripper upgrade

Only 3 things needs to be done for upgrade

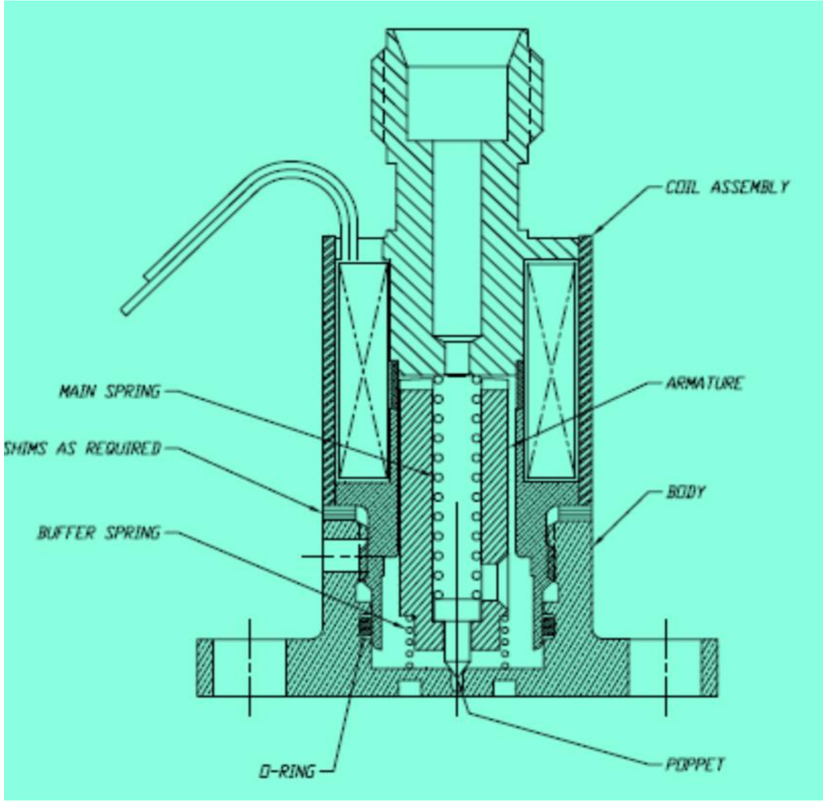
To upgrade the present gas stripper setup we propose the following:

- **To add a gas catcher tube placed on the gas jet axis at some distance downstream from the nozzle exit and assembled on the top flange of the main gas stripper chamber.**
- **To pump gas out of the gas catcher tube, to connect its output through a flexible bellow with an additional relatively small Roots pump of 250 m^3/h capacity.**
- **The pulsed gas stripper operation is simply realized by implementing a commercially available fast gas valve directly connected to the nozzle entrance.**

Proposal for UNILAC gas stripper upgrade

Pulsed valve design

We suggest to use this commercial solenoid-driven pulsed valve:https://www.parker.com/Literature/Precision/Fluidics/Miniature/Solenoid/Valves/PulseValves.pdf



These valves are used for the pulsed gas-jet internal targets production at

- **Antiproton Decelerator (AD), CERN and**
- **Low-energy Storage Ring (FLSR), Goethe University, Frankfurt**

Proposal for UNILAC gas stripper upgrade

Nozzle and gas catcher tube design

Conical Nozzle geometry		
Nozzle parameter	GSI nozzle	New nozzle
Throat diameter	0.85 mm	1.0 mm
Exit diameter	5.0 mm	8.0 mm
Length	13.75 mm	40 mm

We suggest to use this nozzle

The gas catcher tube has a conical entrance part measuring 28 mm in length with entrance and exit inner diameters of 40 mm and 50 mm, respectively. The thickness of the catcher tube wall is not critical.

Proposal for UNILAC gas stripper upgrade

Computer Experiments – VarJet code

The operation of the proposed upgraded gas stripper we investigated by means VarJet code based on the solution of a full system of time-dependent Navier-Stokes equations described in

V.L. Varentsov, A.A. Ignatiev, Numerical investigations of internal supersonic jet targets formation for storage rings, Nucl. Instrum. Methods Phys. Res. A 413(1998) 447–456

- **A full set of input parameters for simulation includes:**
  - ✓ **a geometry of the device under the study;**
  - ✓ **a sort of the gas, or composition of the gas mixture;**
  - ✓ **a stagnation gas pressures and temperatures;**
  - ✓ **a background pressure in the vacuum chamber.**
- **There are no any free parameters in the model. Therefore, results of calculations can be directly compared with experimental data without the using of any fitting.**

Proposal for UNILAC gas stripper upgrade

Continuous Nitrogen jet operation

Calculation variants:

1. GSI nozzle at 4-bar stagnation pressure
2. GSI nozzle + gas catcher at 4-bar stagnation pressure
3. New nozzle + gas catchet at 4-bar stagnation pressure
4. GSI nozzle + gas catcher at 10-bar stagnation pressure
5. New nozzle + gas catcher at 10-bar stagnation pressure

Proposal for UNILAC gas stripper upgrade

Continuous Nitrogen jet operation

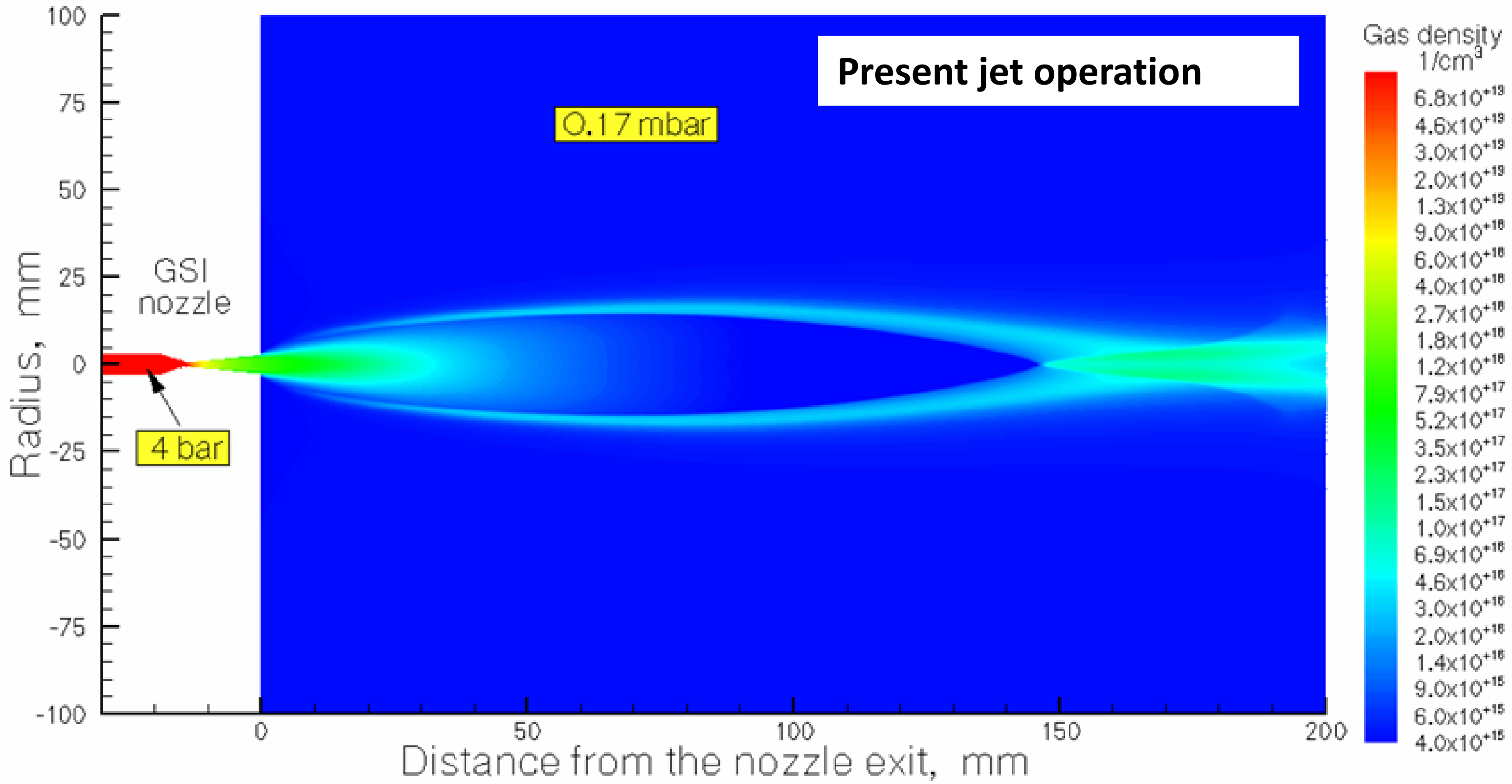
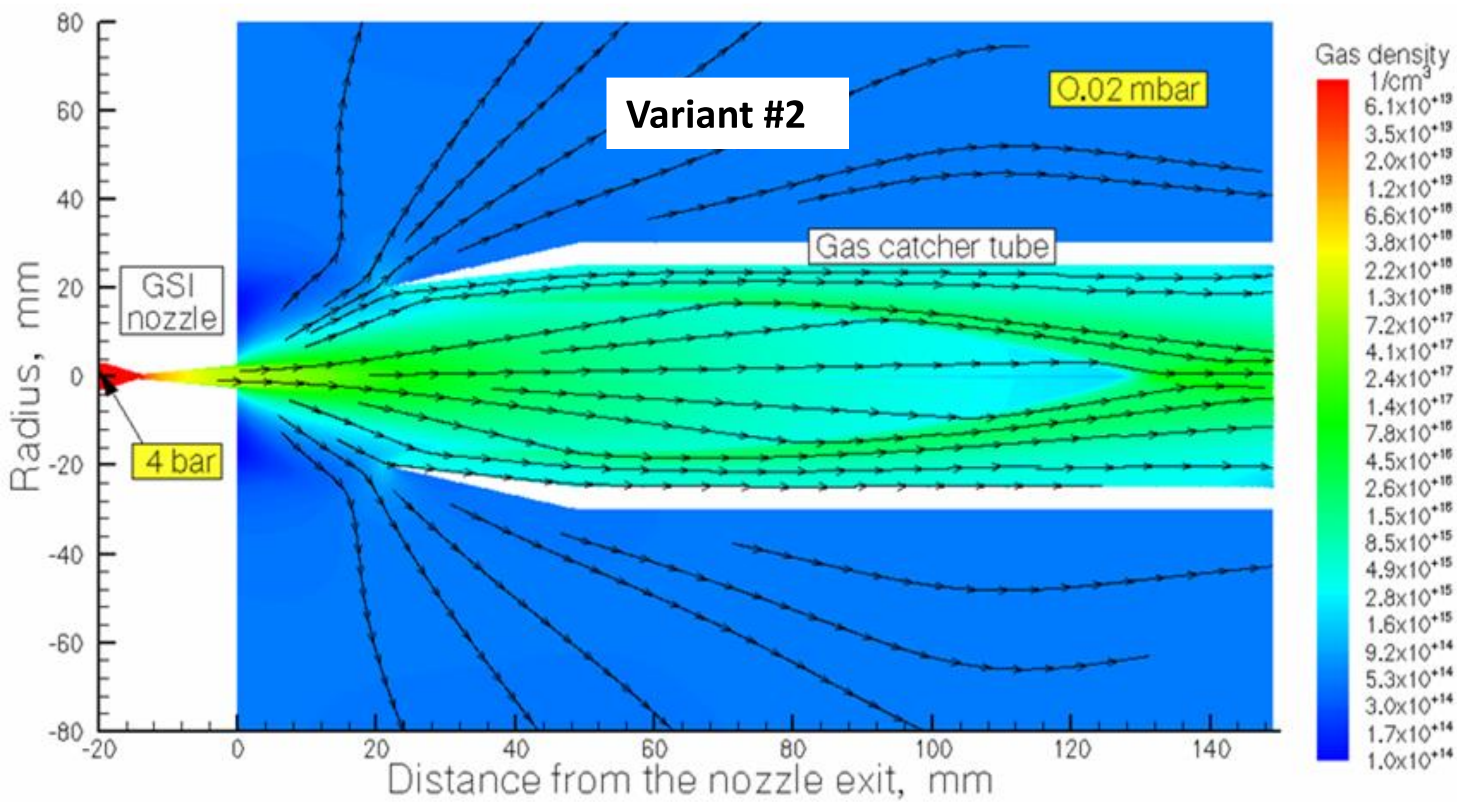


Figure 5. The result of the gas dynamic simulation of the nitrogen density flow field for the GSI nozzle. The stagnation pressure and temperature are P_0 = 4 bar and T_0 = 296 K, respectively. The calculated background pressure in the main stripper chamber is P_{bg} = 0.17 mbar for nominal Roots pumping speed of 2222 l/s..

Proposal for UNILAC gas stripper upgrade

Continuous Nitrogen jet operation



<u>Figure 6</u>. The result of the gas dynamic simulation of the nitrogen density flow field for the GSI nozzle + gas capture. The stagnation pressure and temperature are P_0 = 4 bar and T_0 = 296 K, respectively. The background pressure in the main stripper chamber is P_{bg} = 0.02 mbar. The black arrow lines show the gas flow directions.

Proposal for UNILAC gas stripper upgrade

Continuous Nitrogen jet operation

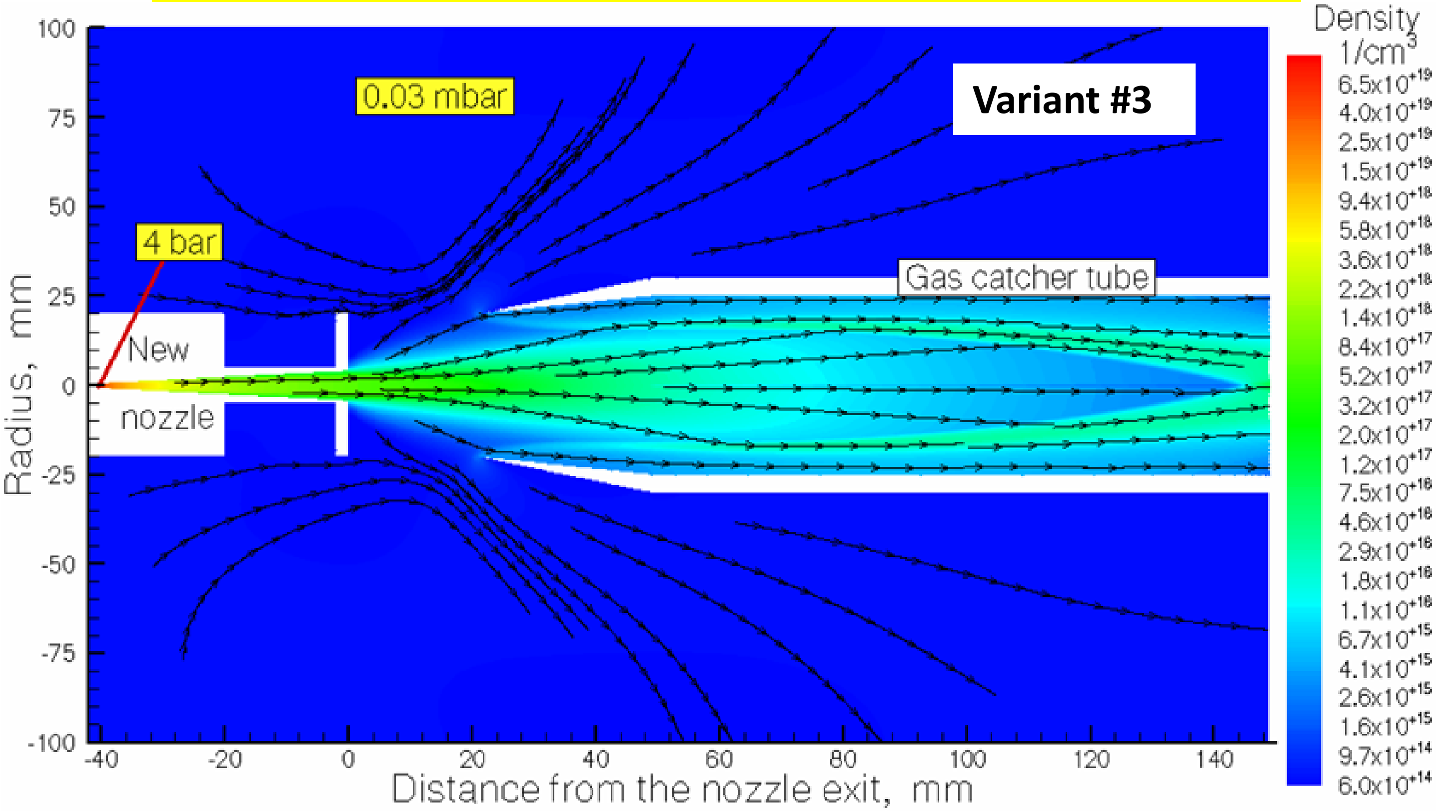
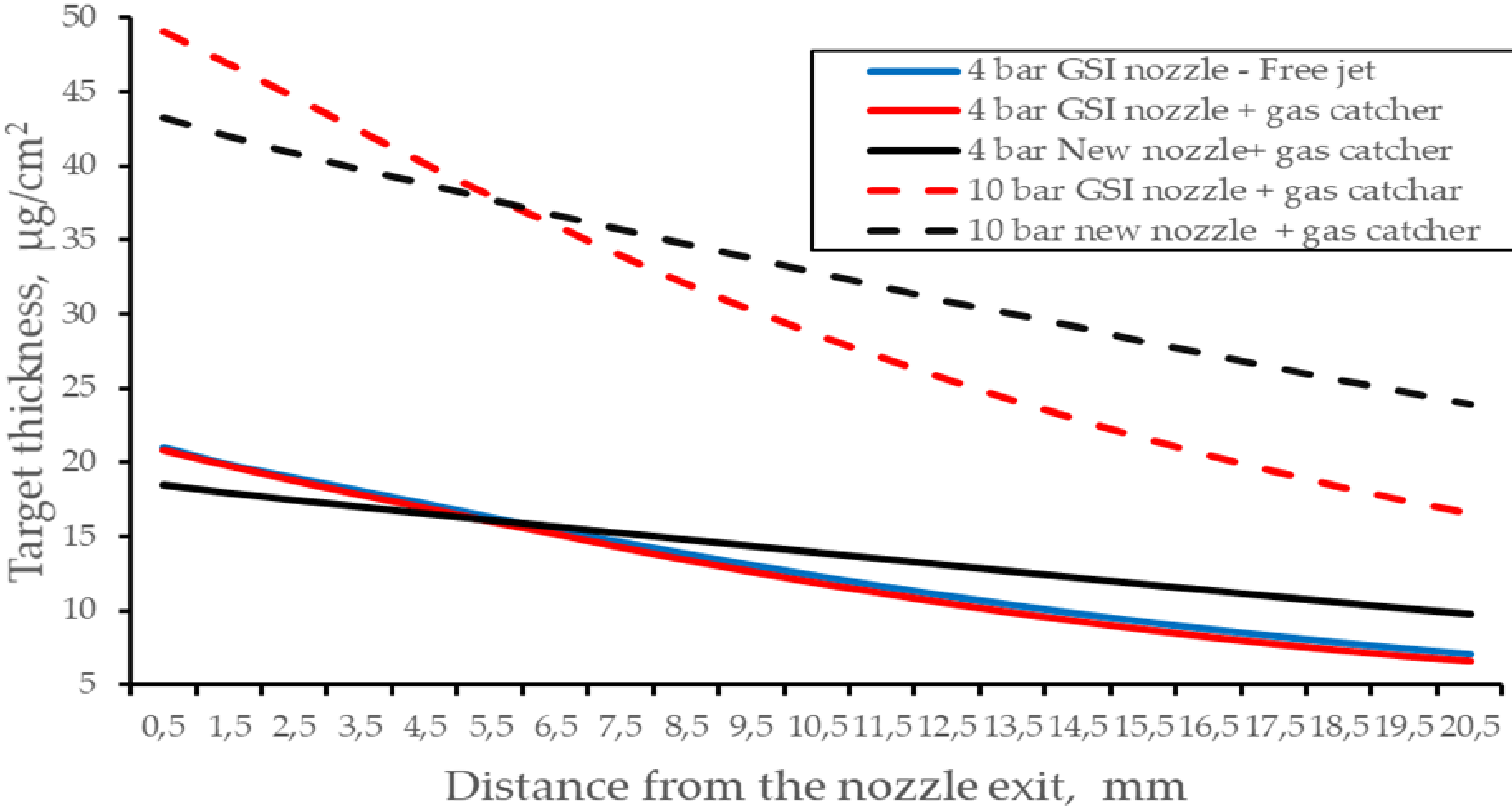


Figure 7. The result of the gas dynamic simulation of the nitrogen density flow field for the calculation for New nozzle + gas capture tube. The stagnation pressure and temperature are P_0 = 4 bar and T_0 = 296 K, respectively. The background pressure in the main stripper chamber is P_{bg} = 0.03 mbar. The black arrow lines show the gas flow directions.

Proposal for UNILAC gas stripper upgrade

Continuous Nitrogen jet operation



<u>Figure 8</u>. The results of calculations of the nitrogen target thickness as a function of distance from the nozzle for different variants of the gas stripper operation with a continuous nitrogen gas jet. The nozzle temperature is T_0 = 296 K for all calculation variants.

Proposal for UNILAC gas stripper upgrade

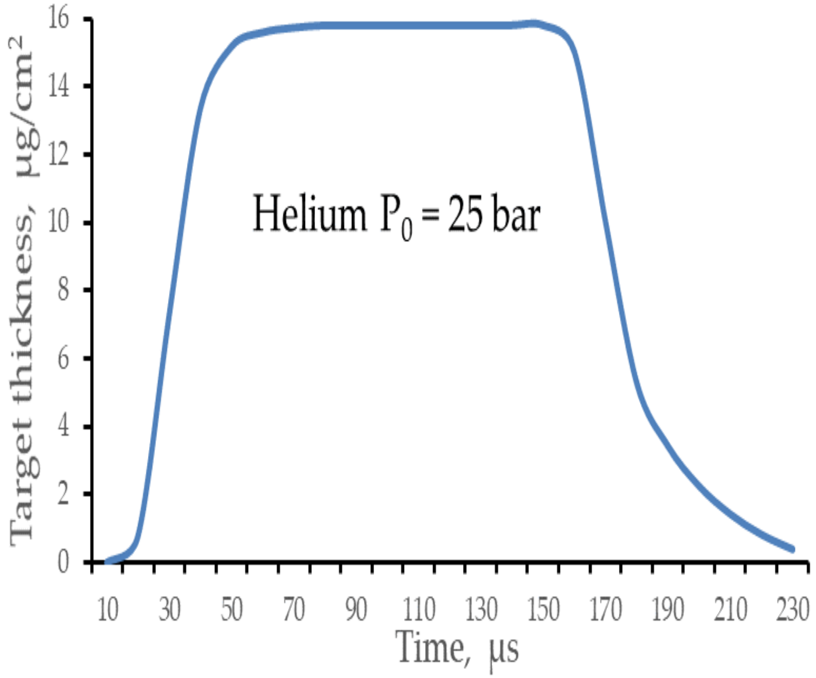
Continuous Nitrogen jet operation

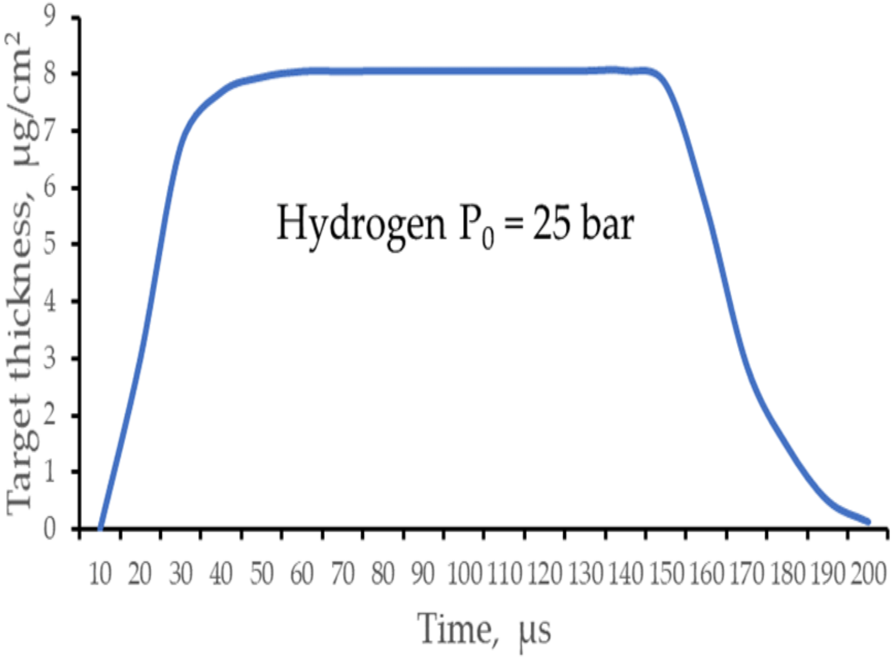
Table 1. The main calculated characteristics of the five variants of the GSI UNILAC gas stripper operation with a continuous nitrogen gas jet. ”Total gas flow rate” is a nitrogen gas flow rate through the nozzle. “Background pressure” is a pressure value in the main stripper chamber. “Gas catcher efficiency” is a fraction of the total gas flow rate pumped through the gas catcher tube. “Averaged target thickness” is a nitrogen target thickness averaged over the gap between the nozzle and catcher tube entrance.

Calculation variant	Total gas flow rate [mbar l/s]	Background pressure [mbar]	Gas catcher efficiency [%]	Averaged target thickness [μg/cm²]
#1	377.7	0.17	-	12.98
#2	377.7	0.021	87.8	12.54
#3	522.2	0.027	88.6	13.97
#4	944.3	0.055	87.0	30.25
#5	1305.5	0.057	89.1	33.06

Proposal for UNILAC gas stripper upgrade

Pulsed gas jet stripper operation





<u>Figure 9.</u> The result of the calculation of the time profile of the averaged helium target thickness. The gas valve opens at zero time and closes at 150 μs.

<u>Figure 13.</u> The result of the calculation of the time profile of the averaged hydrogen target thickness. The gas valve opens at zero time and closes at time 140 μs.

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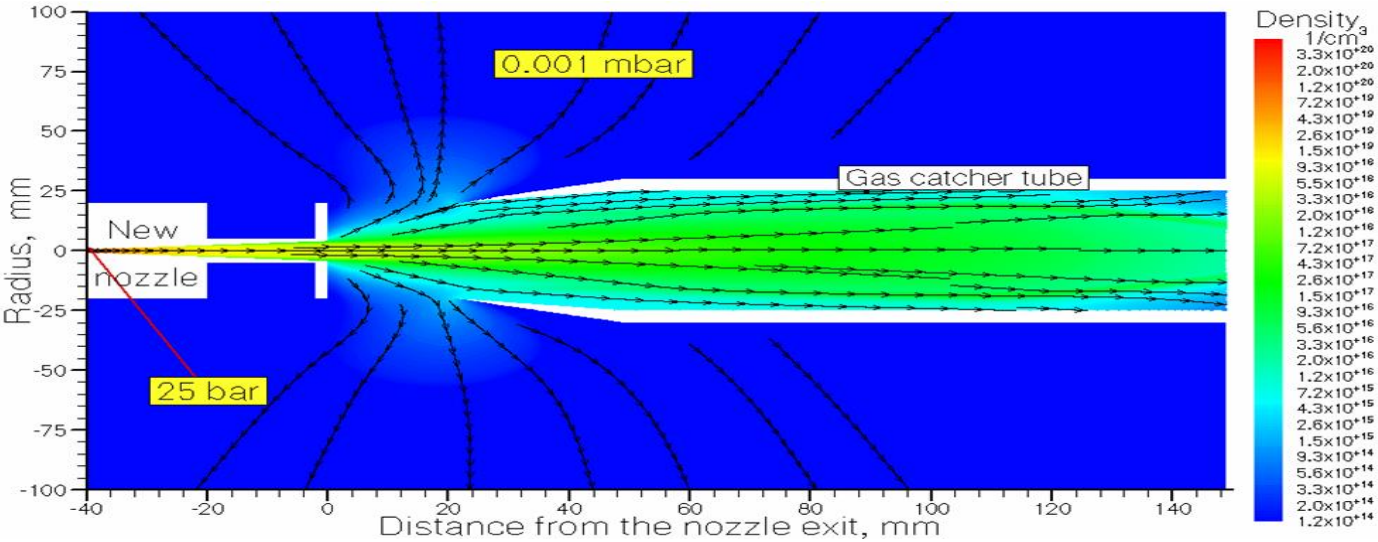
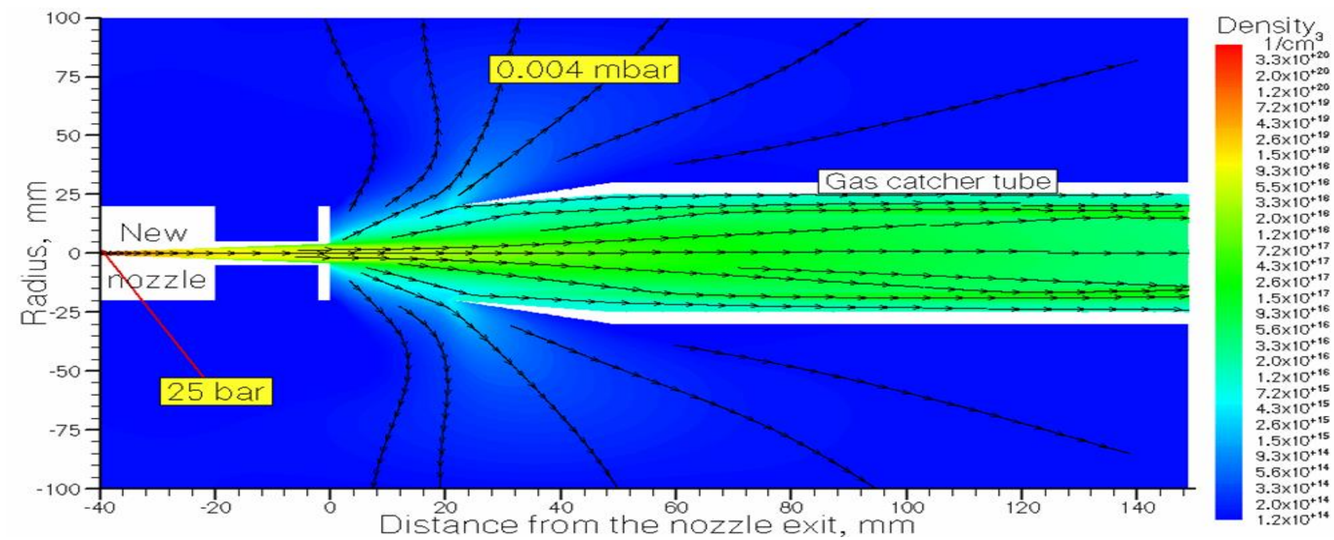


Helium

50Hz & 200µs

Gas catcher efficiency = 97.9%



Hydrogen

50Hz & 200µs

Gas catcher efficiency = 93.4%

Pulsed gas jet stripper operation

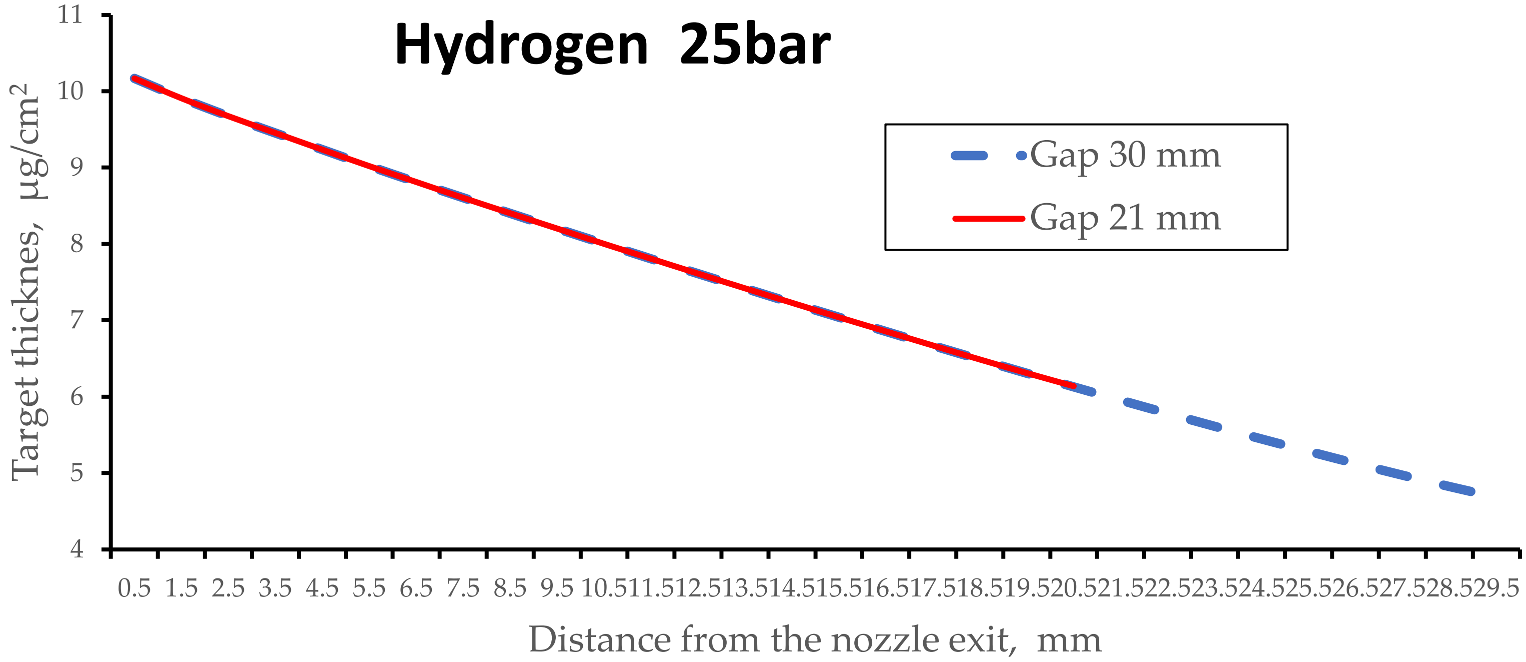


Figure 17. The results of the gas dynamic simulations of the pulsed hydrogen target thickness for different gaps between he nozzle exit and the gas catcher tube entrance.

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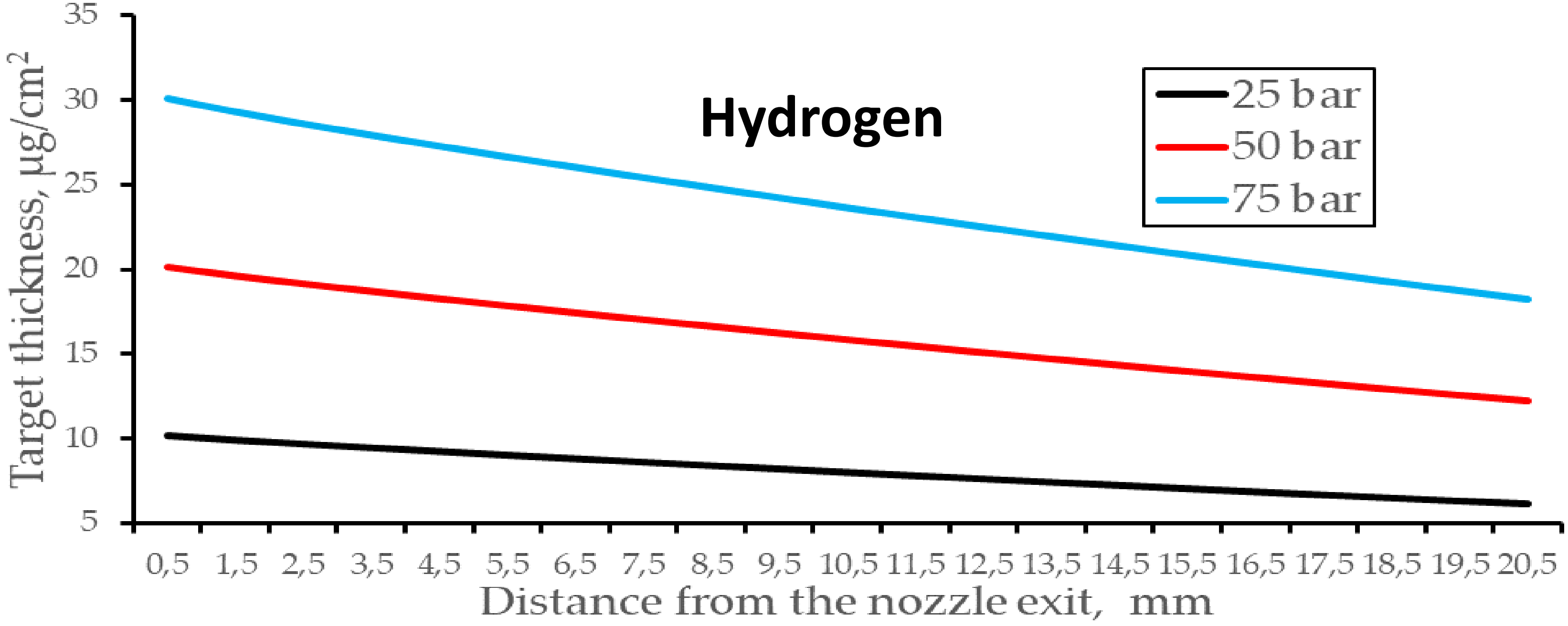

<u>Figure 21</u>. The results of the gas dynamic simulations of the pulsed hydrogen target thickness as a function of distance from the nozzle exit for stagnation pressures of 25 bar, 50 bar, and 75 bar.

Conclusion and Outlook

- ✓ **There are many reasons to believe that an implementation of the presented new version of the UNILAC gas stripper should not be expensive and too time consuming.**
- ✓ **The time is right to start these works and then (very soon) use a new gas stripper in Phase-0 and Early-Science FAIR programs.**
- ✓ **I'll do my best to help the UNILAC team with this upgrade.**

Thank you very much for your attention