Influence of Skimmer Geometry on a Gas-Jet Curtain for Use in a Novel Beam Profile Monitor

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Abstract

Growing interest in the development of low energy storage rings calls for new **beam diagnostics** technologies to be developed, in order to match the strict requirements on high vacuum and very low beam perturbation. When it comes to **profile monitoring**, a possible solution is constituted by a neutral **supersonic gas jet target shaped into a thin curtain** and two-dimensional imaging of the gas ions created by impacting projectiles. Such monitor allows both efficient evacuation of the injected gas and simultaneous determination of both transversal profiles.

To provide a deeper understanding of the fluid dynamics of the curtain shaped gas-jet, we suggest in this work, both on mathematical and applicative grounds, the relevant features to be assessed when evaluating the quality of the gas-jet curtain. We then present a study, based on computational fluid dynamics simulations, on the **effects of geometrical design** of the nozzle-skimmer system, showing how variations of the geometry can have considerable effects. In particular we discuss the influence of skimmer geometry on velocity distribution, curtain height to width ratio and secondary shock waves pattern.

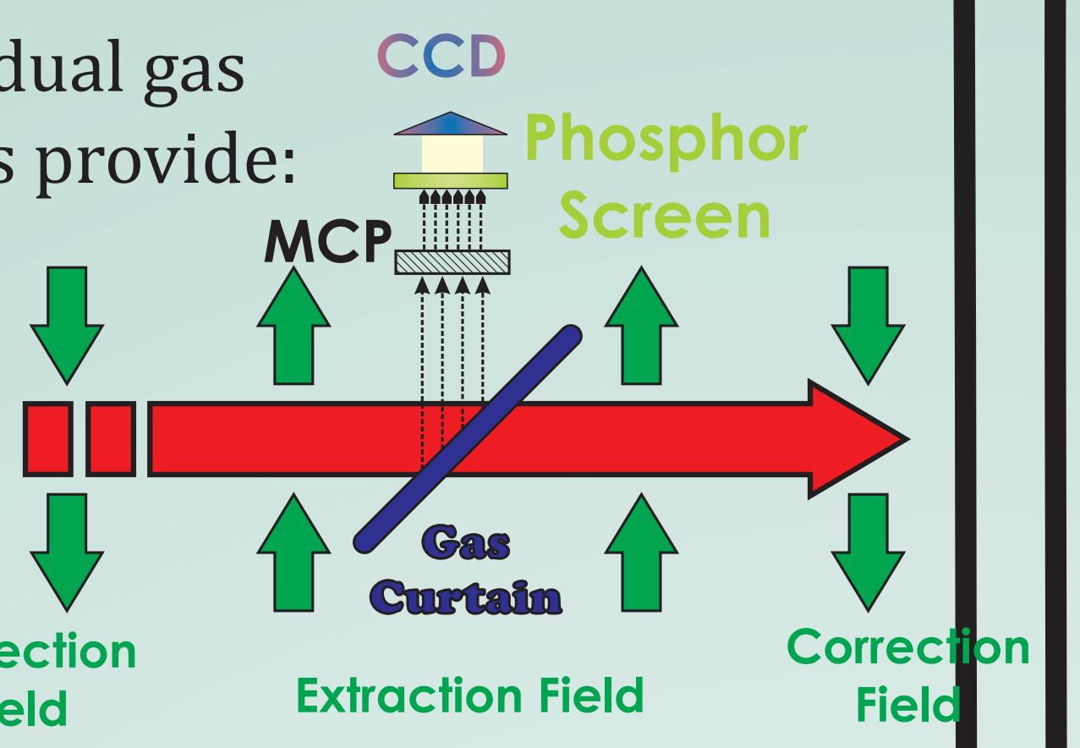
Motivation

0. Basics: To shape the curtain we use rectangular nozzle slit and skimmer instead of circular nozzle and skimmer, as they are used for axissymmetric jets.

1. Profile Monitor:

Design of a profile monitor for ultra high vacua, where residual gas monitors are no longer applicable planar supersonic jets provide:

1. low perturbation
2. easy evacuation due to high directionality
3. wide curtain (40 mm) for monitoring cooling process



Working principle

2. Theoretical Knowledge

Provide an in-depth study of the planar flow, completing the already well established knowledge about axissymmetric jets used in atomic and nuclear physics.

3. Future Applications: Beam Shaper

Controlled fine shaping of the jet flow and crossing with unwanted areas of the projectile beam beam shaping, removal of halos.

Monitored Parameters

Involved Fluid Dynamics problem to be solved numerically: 3D computer simulations are hence run using the GDT code. A set of well defined, stable observables has to be chosen to assess numerically the quality of the curtain.

1. Relevant Physical Quantities

For an ideal gas with constant C_p, in an isentropic process, (well approximated for a supersonic expansion) a set of expressions might be derived yielding temperature, pressure and density, as a function of normalized velocity (Mach number). Hence all thermodynamic variables can be computed once M is known, implying that M becomes our most relevant variable.

2. Choice of Observables

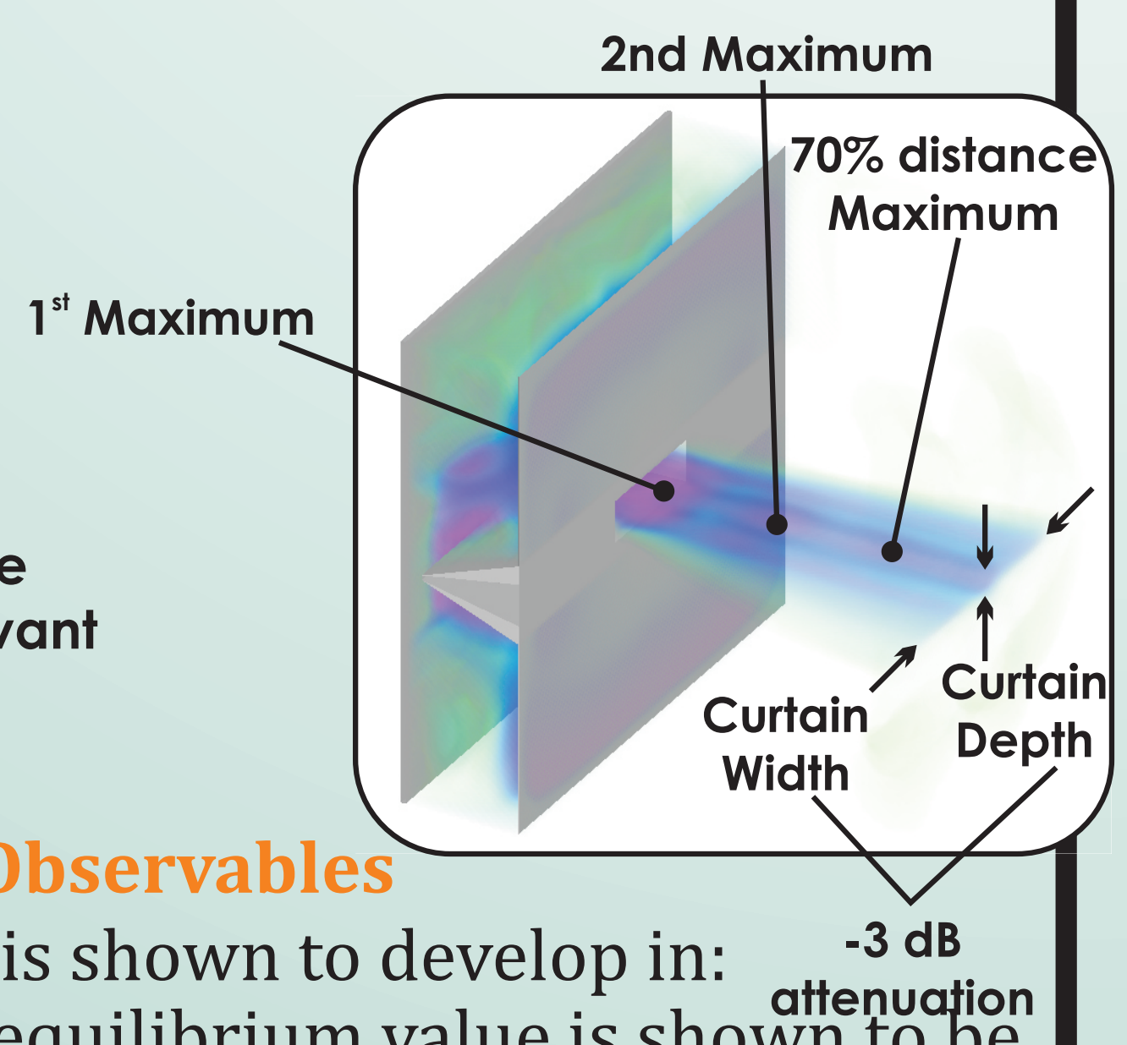
All simulations show results for M, and the following observables, as shown in the figure, are recorded:

Variable	Abbrev.
Max. M	M_{max}
Coordinates Max. M	CM_{max}
2nd Max.	2^{nd} M_{max}
Coordinates 2^{nd} Max. M	2^{nd} CM_{max}
Max at 70%	M_{max} 70%
Curtain Depth	D
Curtain Width	W

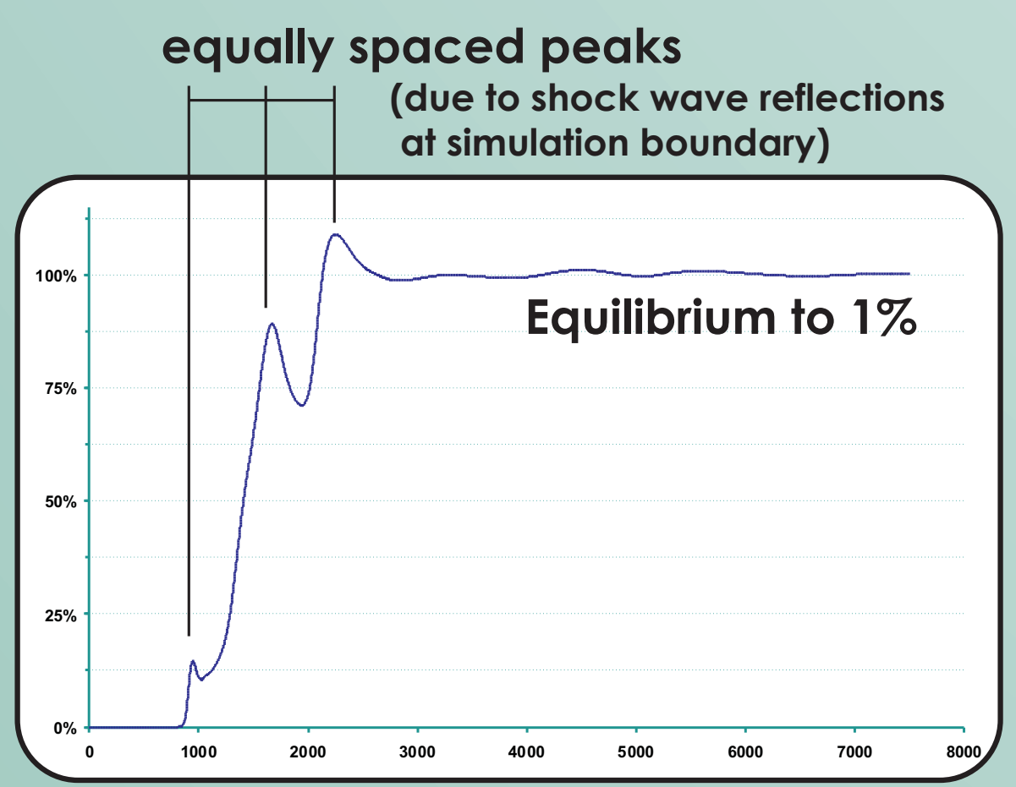
Max. M, Coordinates Max. M, 2nd Max., Coordinates 2nd Max. M: Provide indication on expansion cooling efficiency

Max at 70%: Provide indication on terminal value of M

Curtain Depth, Curtain Width: Combined provide relative thickness of the curtain, relevant to resolution estimations



3. Convergence to Equilibrium and Stability of Chosen Observables



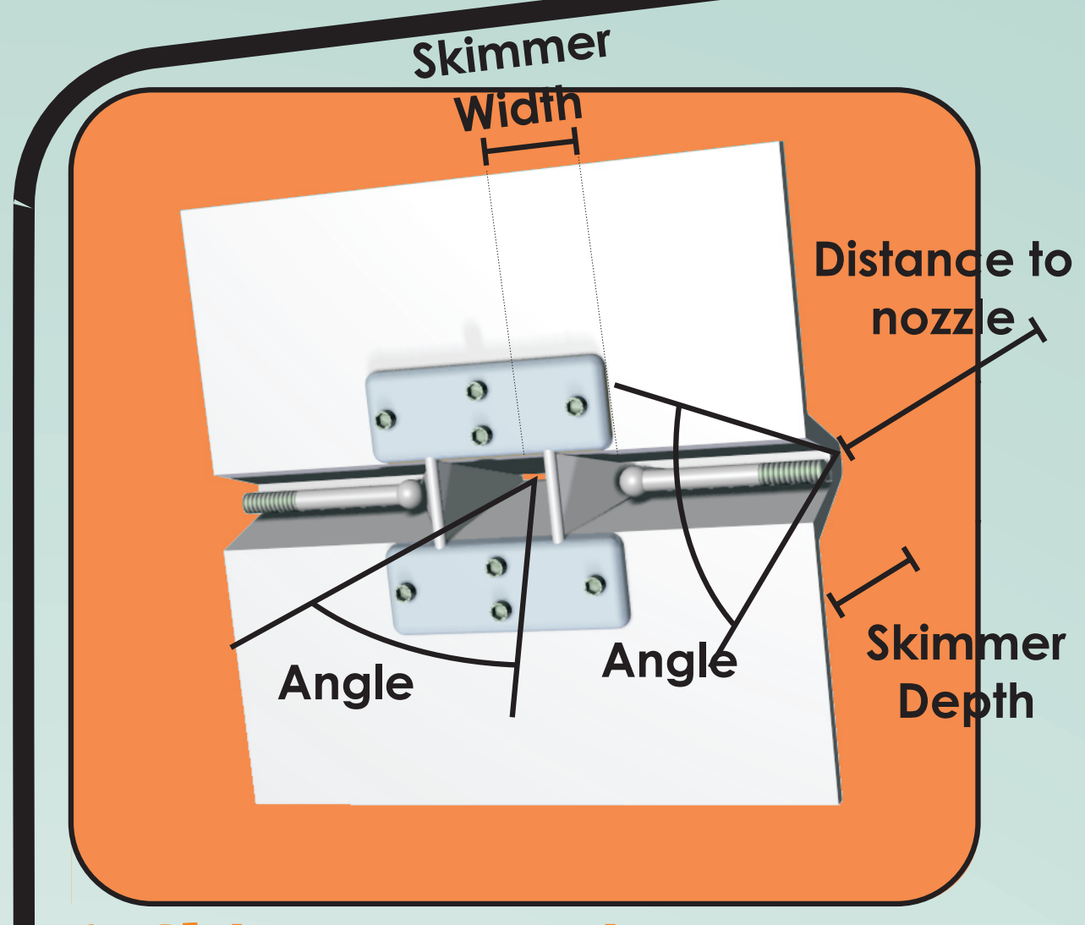
An equilibrium condition is shown to develop in:

- Time: Convergence to equilibrium value is shown to be fast enough (95% accuracy within 7500 simulation steps in all cases) to allow fast computation and hence wide statistics.

- Space: Trends are preserved even after changing simulation grid finesse over a factor of 10.

Curtain Shaped Gas Jet

Curtain Shaping



1. Skimmer Design

Flexible skimmer design to allow investigation of different parameters:

_ - Aperture angle in the direction of curtain width.

_ - Aperture angle in the direction perpend. to curtain width.

SW - Linear aperture of the skimmer slit

SD - Skimmer Depth

Dist - Distance to nozzle

2. Curtain Shaping

a) Relative Orientation Skimmer-Nozzle

Simulations show that much better results in terms of expansion efficiency and curtain shape are obtained for nozzle slit oriented perpendicular to skimmer slit.

b) Observed Trends

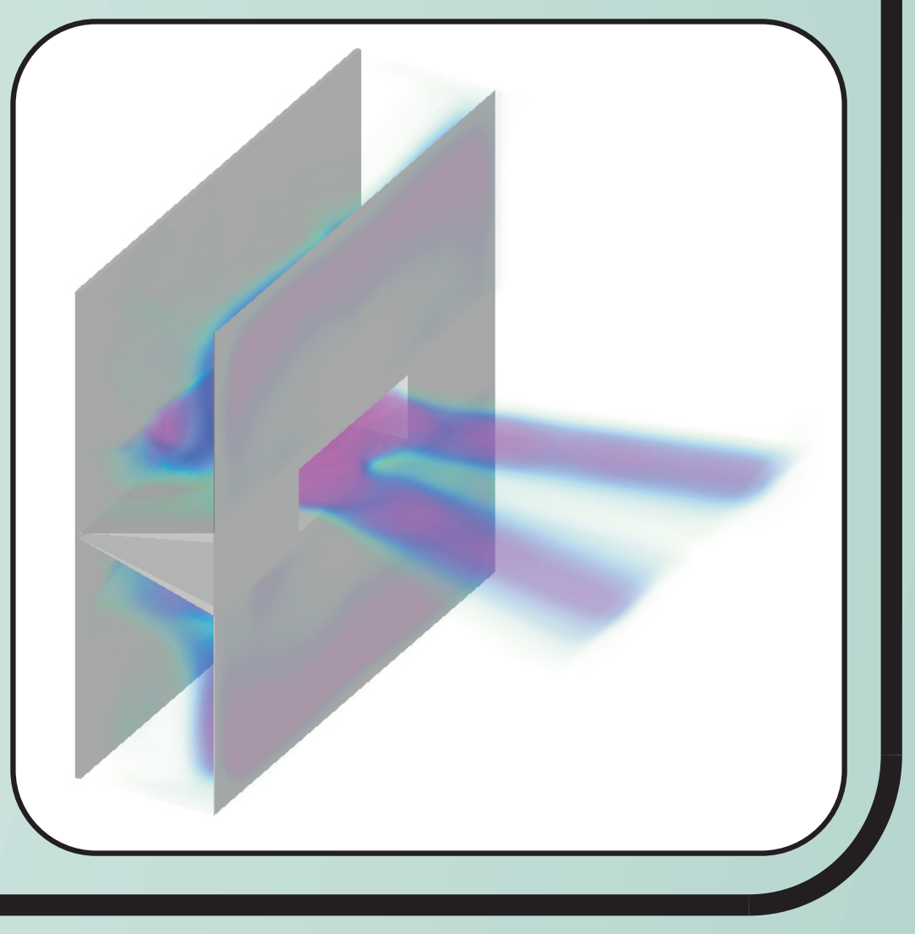
i. Strong trends (bold arrows).
ii. Weak trends (thin arrows).
iii. Dependence on other parameters (blue circles).

	M_{max}	CM_{max}	M_{max}70%	D	W
	SD	SD	↘	↘	↗
	○	○	↘	◡↗	→
SW	↗	↗	↘	↘	↗
SD	○	○	○	◡↗	⌒↘
Dist	⌒↘	↗	⌒↘	○	○

Amongst the conclusion drawn, we highlight:

- Increasing leads to improved geometry (higher W/D) but decreases expansion efficiency (lower M_{max}70%).
- Skimmer width can be increased for improved geometry.
- Distance nozzle-skimmer can be optimised to yield best expansion efficiency (maximum M_{max}, M_{max}70%).

3. Splitting Feature



Parameters can be chosen so that the curtain splits in two well separated diverging flow tubes.

Divergence of the flow tubes, intensity, width and density in the middle region can all be varied by proper choice of the system parameters. Very interesting for application to beam scraping.

Outlook

Experimental Validation of CFD Simulations

1. Experimental Chamber

a. Vacuum chamber equipped with piezo-driven, multicomponent skimmer system, allowing fine modifications of the geometry.

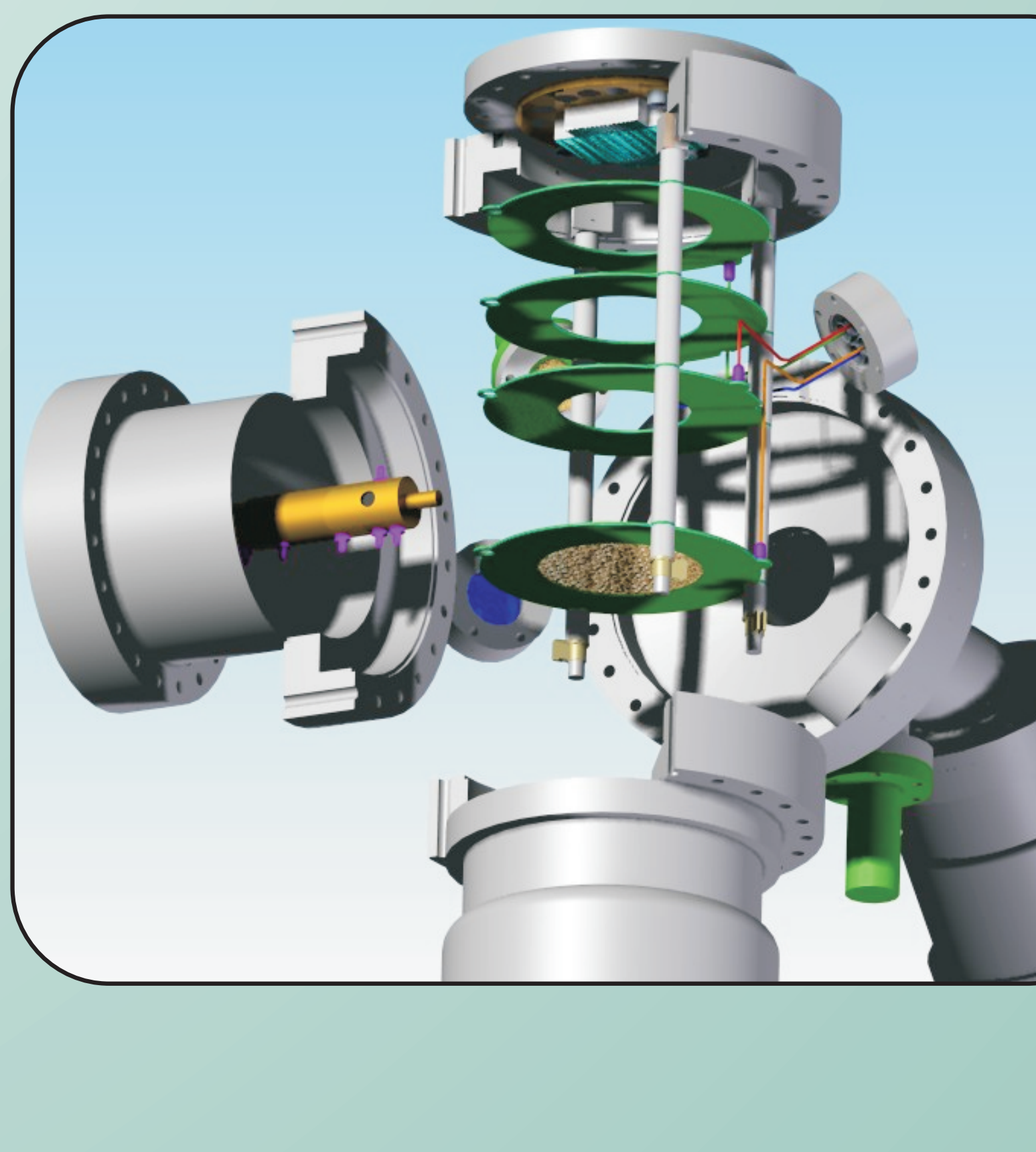
b. Prototype evacuation system included for efficiency testing.

c. Chamber houses movable mounts for sensing equipment.

2. Sensing System

a. Electron gun + MCP detector for density measurements.

b. Laser velocimeter for Mach Number measurements and cross check.



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