Optimization Studies on Planar Supersonic Gas-Jets for Beam Profile Monitor Applications

M. Putignano†, C.P. Welsch, Cockcroft Institute and Liverpool University, UK.

Why is this work important?

- Tool for beam transverse profile monitoring non-perturbing to both beam and vacuum levels needed in low energy storage rings, due to:

Higher interaction σ with residual gas ⇒ UHV needed to preserve beam: 10^{-13} mbar

Multi pass operation ⇒ perturbation to beam unacceptable

BUT

State of the art techniques fail!

- Conventional planar gas-jet creation ⇒ thick curtain (= low resolution) & poor pumping.
- Magnetic focusing of curtain needs strong (1.3 T) magnetic field ⇒ disruption to low energy beam

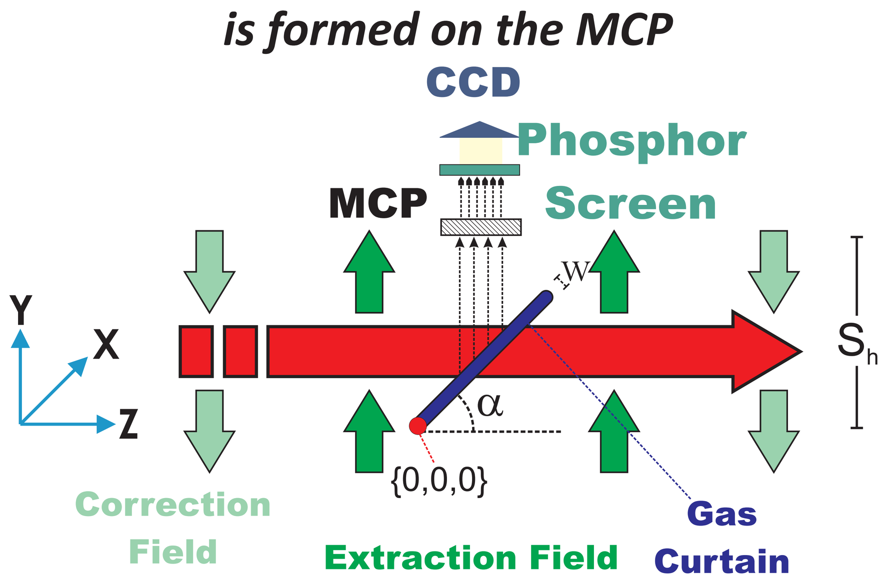
⇒

Novel, optimized curtain creation system needed.

MONITOR IDEA

- Thin curtain-shaped jet of neutral atoms ⇒ target for incoming beam.
- Beam ionizes the gas.
- Gas ions extracted vertically and imaged on position sensitive detector (MCP + Phosphor Screen)
- Different y coordinates of ionizing projectile ⇒ different positions on MCP.

⇒ ***An image of the transverse profile is formed on the MCP***



What is this work about?

1 - Assess the impact on jet structure of:
   a) nozzle-skimmer geometry
   b) thermodynamic variables (pres. and temp.)

⇒ ***Many variables: computation time becomes an issue!***

2 - Identify suitable quality factors for the curtain

3 - Optimize code to reduce computing time:
   a) find min time for gas to reach equilibrium
   b) optimize boundary conditions

4 - Describe behavioral trends spotted

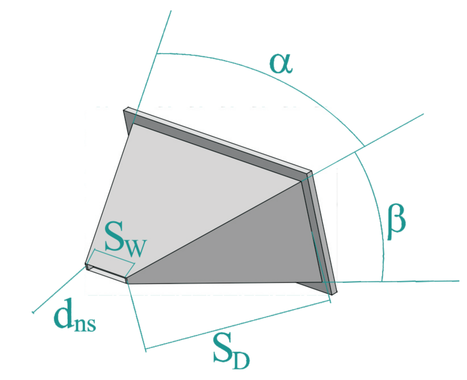
5 - Identify exploitable behaviors (e.g. split curtain)

6 - Propose optimized nozzle-skimmer system

Simulation variables

5 Geometric variables: 1

- Angles α and β
- Skimmer Width **SW**
- Skimmer Depth **SD**
- *Nozzle-Skimmer Distance d_{ns}*



2 ***2 Thermodynamic variables:***

- *Pressure Ratio*
- *Temperature*

Observables

- **Mach Number:** relates to expansion efficiency and internal temperature.
- **Curtain Depth D:** curtain short dimension ($\sigma_{density\ profile}$)
- **Curtain Width W:** curtain long dimension ($\sigma_{density\ profile}$)

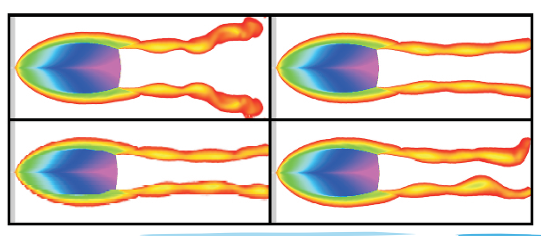
Abstract

MOTIVATION & STATE OF THE ART → For **transverse beam profile monitoring applications** where ***low beam perturbation*** and ***bi-dimensional imaging*** is required, we propose an ionization monitor based on a neutral **gas-jet targets shaped into a thin curtain**. When integrated in UHV systems, such as in the **Ultra-low energy Storage Ring (USR)**, where vacuum preservation is of primary concern, such system present severe difficulties linked to the creation and proper shaping of a high quality gas-jet curtain. Nevertheless, no detailed theoretical study exists in the literature on **planar jet creation through optimized orifice (nozzle) and collimators (skimmer) geometry**.

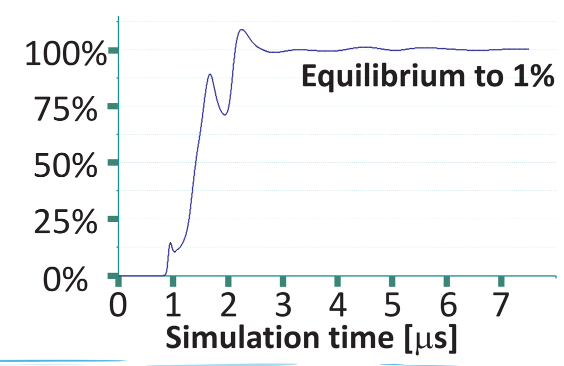
CONTENTS → Investigations into the **generation and evolution of the jet** with the commercial Gas Dynamics Tool (GDT) software and purpose-written C++ analysis modules are presented. By means of extensive **numerical analysis** the whole variable space is mapped, leading to the **proposal of a novel nozzle-skimmer system geometry**, whose advantages over the performance of traditional methods are descibed. It is also shown that variable nozzle-skimmer geometries allow for modifying the gas-jet characteristics in a wide range, including **jet splitting** and **local density modulation**.

Numerics 3

Density profile stability.
Optimized boundary conditions ⇒*below:* density profile at 0.5, 10, 150 and 650 μs.



Time stability.
Right: Density profile time evolution. Equilibrium achieved within 7.5 ms.



Results

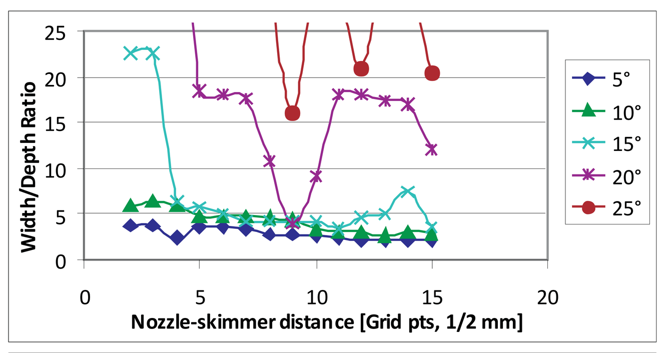
	Mach N.	D	W
α	↘	↘	↗
β	↘	◡↗	→
SW	↘	↘	↗
SD	α	◡↗	⌒↘
Dist	⌒↘	α, β	α, β

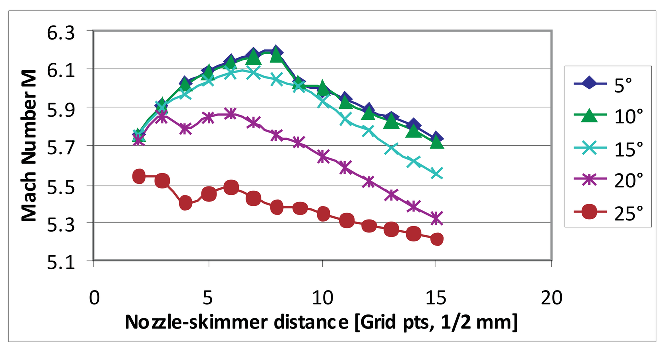
Trends description of the system. 4

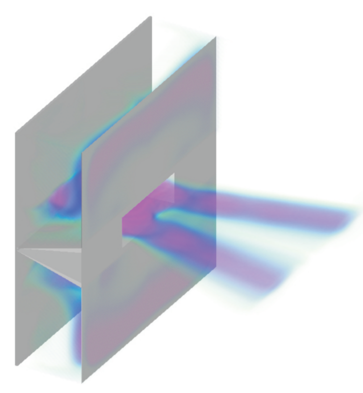
Left in table: trends spotted.
Arrow shows dependence of the column observable when increasing the row variable.
Straight arrow (upward/downward) = linear increase/decrease; bent arrow = parabolic dependence. Orange = well defined trends (Pearson value > 90%), black = less evident (Pearson value >75%).

Right: ***Examples of spotted trends.***
Trade off in choosing α, curve family parameter in the plots: increasing α improves width depth ratio (upper plot), but decreases expansion efficiency (Mach number, lower plot).

An optimum condition exists for the nozzle-skimmer distance => Mach Number (and hence expansion efficiency) maximization possible.







Left: ***Different operation modes available*** 5
large α/β ratios, small nozzle-skimmer distance and high pressure ratios => "split curtain" behavior.
Possible applications: beam halo monitoring avoiding saturation or, in storage rings (because of multi-pass operation), even halo scraping.

6

Different geometries tested and compared with conventional system (scraping out of an axissymmetric jet with collimators):

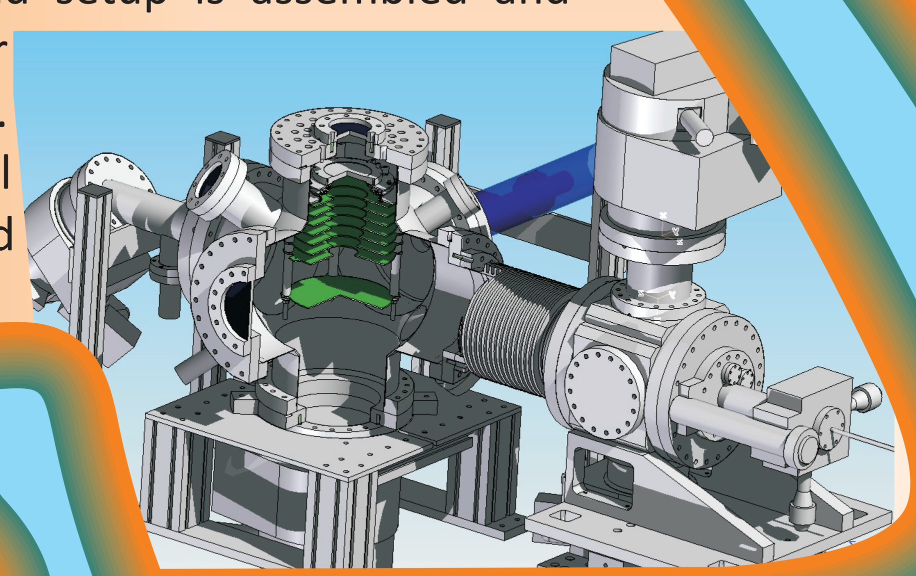
⇒***Novel nozzle skimmer system proposed:***

Slit nozzle and slit skimmer oriented perpendicular to each other: in optimized configuration increase by factor of 2 in resolution and factor of 13 in accuracy as compared to conventional systems!

Outlook

Experimental benchmark of results.

The vacuum vessels, signal acquisition electronics and detectors needed for the experiments are manufactured and setup is assembled and operating in our laboratories. Experimental results expected by summer 2011.



Contact

www.quasar-group.org

massimiliano.putignano@quasar-group.org

Tel. +44 01925 804056

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