Design and simulation of window-less gas jet target for experimental nuclear physics

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Introduction

Recent measurement for the gamma transition between the 4^+ and 2^+ states of ^{8}Be in the ^{4}He+^{4}He reaction using a gas cell target addressed the first electromagnetic signature of its dumbbell-like shape [1]. In the gas cell target the chamber is isolated from the beam line vacuum using Kapton foils at the entry and the exit, which is the main source of background for the gamma ray measurement. There is a need to develop the windowless gas jet target for the measurement of radiative capture cross section. The development of windowless gas jet target is also useful for nuclear physics experiments for the measurement of cross sections of astrophysical interest, production mono-energetic neutron by inverse kinematics using gaseous targets.

High density supersonic gas-jet target (JENSA) [2] of thickness (10^{19} atoms/cm^2) for gaseous atoms (H, He, N, etc) is used in experiments with radioactive beams. The LUNA (a laboratory for underground nuclear astrophysics at Gran Sasso) investigates nuclear fusion reactions at stellar energies and synthesis of the elements in stars using various gas jet targets [3] of thicknesses from 10^{16} atoms/cm^2 to 10^{19} atoms/cm^2.

In this paper, a design of the windowless gas jet target and the simulation to optimize the design parameter of the nozzle which is basically shaping the gas jet target are discussed.

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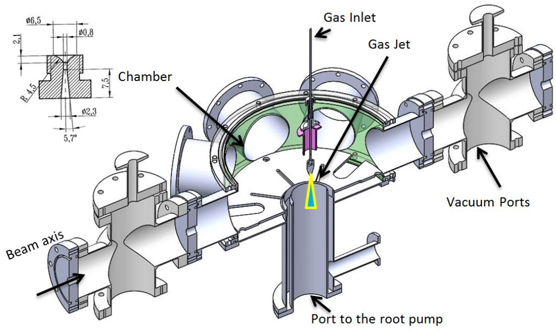

FIG. 1: Schematic of windowless gas jet target and Laval nozzle for gas jet assembly

Concept design of gas jet target

The schematic of windowless gas jet target is shown in Fig. 1. The gas jet target consists of the target chamber with gas injection through Laval nozzle, the gas receiving system with vacuum pumps and the differential pumping system on both beam entry and exit of the chamber. The particle accelerator operates in high vacuum(10^{-7}-10^{-8} mbar). The gas jet target acts as source of big leak to the vacuum system of the accelerator. The multiple stage differential pumping system helps in maintaining the vacuum without loading on accelerator. The vacuum system includes high speed root pumps, turbo pumps, diffusion pumps along with suitable backing pumps. The vacuum gauges will be used at various stages for monitoring the gas pressure. The supersonic free gas jet is produced by injecting high pressure gas (1-5 atm) in to the scattering chamber through a special Laval nozzle, which generates the required gas thickness and shape. It produces supersonic free jets inside a scattering chamber, the secondary gas load is reduced by gas

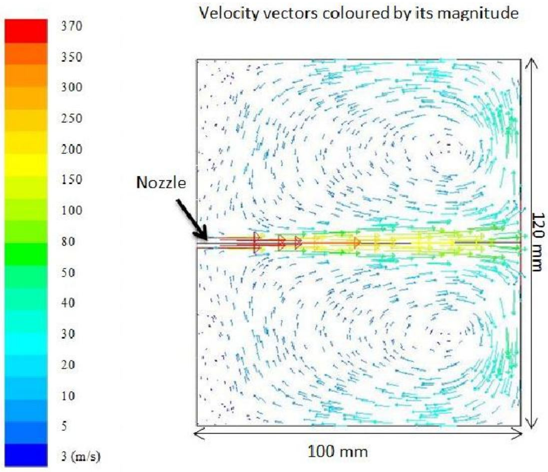

FIG. 2: Circulation of gas molecules in the chamber where the colour signifies the magnitude of velocity vector.

exhaust system, built concentrically around the gas jet and it allows the unrestricted access to the target area. Initially, the idea is to use a gas flow-through system (Gas will be vented out through root pump), but ultimately a gas re-circulation and a cleaning system will be introduced.

Simulation

The gas jet profile has been simulated using a computational fluid dynamics algorithm. The properties of gas jet coming out of nozzle are determined by the geometrical profile of the nozzle, the pressure ratio of the expansion, Pe/Pc (where Pe is the pressure at nozzle entrance and Pc is the pressure in the expansion chamber) and by the ratio of specific heats of the gas. For the primary calculation of the gas jet flow and number density of the target nucleus, simulation has been performed in order to fix the shape and size of the nozzle. In this analysis axial symmetric two dimensional geometry of the nozzle has been selected. The density has been calculated for different inlet pressure.

Result and discussion

Once the Mach-number of the gas, $M = v/c = 1$ is reached at throat portion of the nozzle, the further development

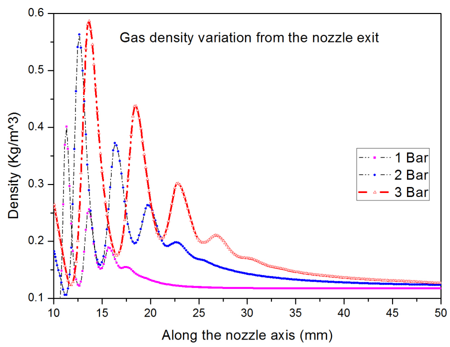

FIG. 3: Simulated density profile for various gas pressure

of the flow in the divergent portion of the nozzle will be shock free if the back pressure is smaller than the pressure at throat. This is also known as under-expanded nozzle (is a function of area ratio). High density under-expanded supersonic free gas jet is aimed for the constant thickness of the gas target for the nuclear experiments. The gas jet through the nozzle creates low pressure around the jet and hence circulation of the gas molecule inside the chamber as shown in the Fig 2. The variation of density along the nozzle axis for different pressure is shown is Fig 3. There are fluctuations in the density just after the nozzle exit, but after certain distance the density reduces smoothly. The number of target nuclei is found to be 10^{17} atoms/cm^2 which is to be verified by elastic scattering experiment.

References

[1] V.M. Datar et. al, Phys. Rev. Lett. 111, 062502(2013).
[2] K.A. Chipps et . al, Nuc. Inst. Meth. A, 763, 553 (2014)
[3] H Costantini et al, Rep. Prog. Phys. 72, 086301 (2009).