A differentially pumped windowless gas target for FRENA and BARC-TIFR PLF

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1. Introduction:

BARC undertook a long-term project to upgrade the national capabilities in low-energy nuclear physics by developing multiple state-of-the-art instrumentation [1] of which one example is a windowless gas target (WGT). The FRENA facility at SINP was recently commissioned and a gas target is also essential for FRENA [2]. Keeping these in mind BARC-Cotton-SINP collaboration was formed in 2022 and since then we are jointly pursuing projects identified by Santra et. al. In this paper, we describe the initial design of the gas target as shown in Fig. 1, and various design considerations.

2. Design considerations

A WGT consists of a target chamber containing gas of the desired isotope. The main requirement for such a WGT is that gas density is ~10^{17} atoms/cm^2. At such densities, the typical pressure inside the target chamber is 1-5 mbar. However, the connecting accelerator system requires about 10^{-6} mbar of vacuum. To achieve these several differential pumping sections (DPS) are used. A DPS consists of collimators, beam tubes, Roots blower, and turbomolecular pumps (TMP). It is essential that the lengths of DPS are kept as short as possible to avoid scattering of beam from edges of the collimators.

Currently, two types of gas targets are in use. **Type-A** works in the principle of developing a pressure gradient by limiting gas flow with the appropriate choice of conductance. The flow is maintained in the laminar/Knudsen region e.g. LUNA gas target. In **Type-B** a supersonic jet is used, e.g. JENSA shown in the Fig. 2. A density >10^{18} atoms/cm^2 is achieved in a narrow spot. Thus, there is a well-defined zone for beam & target interaction. This improves the angular definition and also satisfies optics requirements if an RMS is used downstream. However, the pressure profile in a jet target is hugely elongated resulting in much high energy loss. As an example, we show the measured pressure profile of the JENSA in Fig. 2 (bottom). The pressure is 1.4 mbar extending over half a meter [JENSA_ORNL]. High energy losses and energy/angular straggling precludes the use of a jet in energy-sensitive applications. The straggling also deteriorates the RMS performance. In fact, this forces jets to be operated at a fraction of their design specifications.

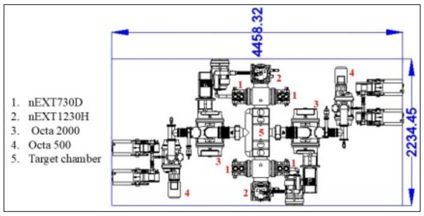

Fig. 1: Layout of the WGT-DPS with design goal of ~10^{17} atoms/cm^2. Working parameter: L=10-15 cm, P= 1- 5 mbar & flow rate <3000 sccm, needs a sound-proof enclosure.

However, we did not opt for Type-B design due to the following reasons: i) lack of relevant technical experience required for execution in jet system, ii) injector pressure for the nozzle is 200-400 psig requiring a recirculation system (RCS), iii) gas mass flow rates are very high, e.g., a full gas cylinder will be emptied in ~2 hrs, but our experience is limited to mass flow <6000 sccm & P <90 psig [4], and also do not foresee use of an RMS at PLF in near future. So, in the present work, we have opted for Type-A design. If we

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add an RCS to this gas target it will also allow us to use the enriched isotopes. In Fig. 3, we show the flow circuit of a high-efficiency RCS (99.6% recirculation), similar to Ref. [4]. In the next section, we will discuss few applications of this gas target. But before that we show some more design details of the gas target in Fig. 5 [3].

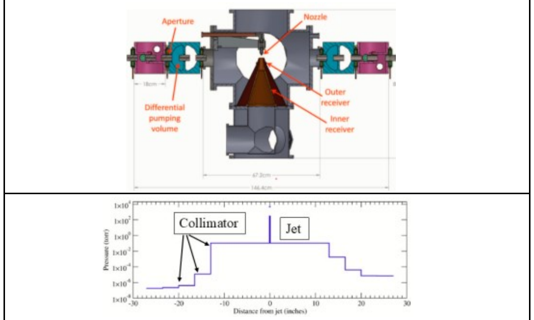

Fig. 2: Pressure profile of the JENSA jet target. Location of the jet and collimators are marked [Ref. link ORNL].

3. Applications of the gas target

(a) WGT for inert isotopes: The PLF cannot deliver inert isotopes as tandem is the injector to the SC-LINAC. Thus, experiments with group-X elements: Ne, Ar, Kr, Xe were never done. A gas target with RCS will enable experiments with all gaseous isotopes including enriched ones. But there is a technical challenge which works in our favor. TRIUMF unfortunately found that all the TMPs of gas target got damaged during an experiment with inert isotope. This was diagnosed to be due to high heat transfer from inert isotopes during the collision with high-speed fans. The TMP gets overheated and damaged. Peiffer has a prescription for inert gases in the manual. It specifies the maximum throughput (sccm) to the heat capacity. This flow limit is lower and can be easily realized with this gas target and proposed RCS. Thus, our gas density will be similar to that in other labs and make PLF experiments competitive.

(b) First Experiment with WGT: The experimental setup to investigate the 2^+ resonance state in ^{8}Be* populated in the ^{4}He+^{4}He reaction is shown in Fig. 5(bottom), & reaction kinematics(top). The θ_{max} <28° (for 2 α's from the 2^+ state). The ASSD (in gas) covers the entire range >10°. The MWPC+IC detects all exiting α′ through DPS <6°. This enables high detection efficiencies with kinematic coincidence. An MQT (magnetic quadrupole triplet) will be used to separate the elastic αs from α′s as the energies of these are very different (8 MeV and 4 MeV).

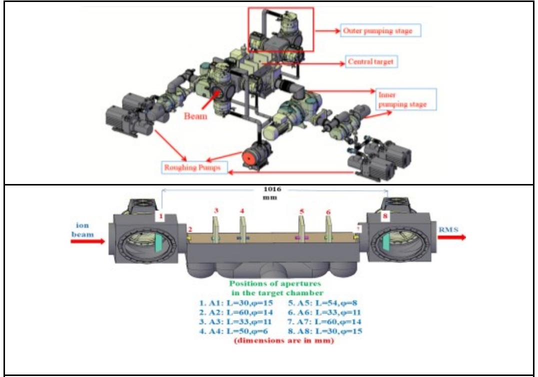

Fig. 4: 3D model of the WGT (top) and internal parts of DPS (bottom). For ensuring precision alignment of internal parts, the assembly is designed from a single block of Al. The shape of the central target section can be varied as per experiments. e.g (i) a cylinder with thin wall for γ/n experiments or (ii) a scattering chamber for charged particle experiments.

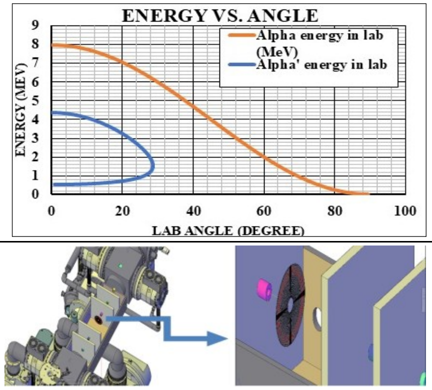

Fig. 5: The reaction kinematics and the experimental setup.

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