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A CONDENSED MOLECULAR BEAM AS GAS TARGET FOR ANTIPROTONS IN THE SPS

CERN-Lausanne-Lund-Michigan-Rockefeller Collaboration

ABSTRACT

With condensed molecular beams of hydrogen as described in literature, very well defined high local gas densities can be produced, which for antiproton beams of 5×10^{11} give luminosities between 10^{30} and $10^{31} \text{ cm}^{-2} \text{ sec}^{-1}$, two orders of magnitude higher than the luminosity estimates for $p\text{-}\bar{p}$ physics in the ISR (10^{28} - 10^{29} , Ref. 11) and one order of magnitude higher than the luminosity for $p\text{-}\bar{p}$ physics in the SPS (Ref. 12). After some minor modifications, the same vacuum system (chamber and pumps) as that for the proposed polarized atomic beam target could be used for this molecular beam apparatus.

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1. DENSITY, LUMINOSITY

In connection with the proposal for the use of a polarized atomic beam as internal target in the SPS¹⁾, the question arose, What luminosity could be achieved with an unpolarized molecular beam?

It is known²⁻⁵⁾ that high intensity molecular beams can be extracted from the central part of the supersonic flow from a miniature Laval nozzle (Fig. 1). These beams have higher intensity, peaked in the forward direction, somewhat higher mean velocity and smaller velocity spread than an effusion or oven beam. Theoretically, the gain should be proportional to M^3 (M being the Mach number)²⁾. However, it appears to be difficult to go beyond $M \sim 4$ or 5, probably because of shocks (free or allocated to the skimmer), which reduce the forward velocity and increase the temperature (random velocity) of the beam⁶⁾.

A typical example from Refs. 4 and 5 is beam No. 2 in Table 1. The corresponding estimates for the polarized atomic beam target are also given in Table 1 (beam No. 1).

The polarized beam is more dense than the supersonic molecular beam because of the lower velocity (cooling to LN_2 temperature) and the focusing by the sextupoles.

Some gain in intensity could be expected from a slit source, but a factor of 10 is probably the maximum.

Substantially higher densities can be produced by cooling the nozzle until the beam gas partially condenses to form small aggregates^{7,8)}. These beams have higher intensity, lower velocity, and lower velocity spread than have ordinary supersonic beams.

Beam No. 3 in Table 1 is an example from Ref. 8. The profile of this beam is shown in Fig. 2 together with a profile of the supersonic beam mentioned above.

Increasing the input pressure to 1 atm and more, increases the intensity further, but the beam becomes unstable, because the gas already starts to liquefy in the input line. This instability can be cured by adding up to 300% He to the input gas (beam 4 in Table 1 with input pressure 2 atm, 50% H_2 , 50% He).

Probably owing to the nozzle separation effect (the He atoms are scattered out of the beam in the nozzle chamber, since they are lighter than the hydrogen aggregates), the beam in the reaction chamber contains only 1.6% He.

Some improvements -- decreasing the nozzle diameter, changing the collimator geometry to produce a beam which is longer in the direction of the SPS beam, but narrower to keep the same gas flow -- might allow us to reach a luminosity of up to $10^{31} \text{ cm}^{-2} \text{ sec}^{-1}$.

For the sake of completeness, the FNAL gas target should also be mentioned⁹⁾. This target uses hydrogen cooled to liquid helium temperatures and achieves a density of 6×10^{16} protons over 1.5 cm length during ~ 200 msec pulses, but with a vacuum deterioration in the accelerator, which could not be tolerated in our case (1.5×10^{-3} Torr near the jet, 4×10^{-5} Torr 10 m away from the jet) (beam No. 5 in Table 1).

In Ref. 8 also results with N_2 and mixtures N_2/H_2 are reported. Densities of 3.5×10^{14} atoms/cm³ could be achieved.

We now estimate the luminosities with the formula:

$$L \sim n \cdot N \cdot f_{\text{rev}} \cdot d ,$$

where

n is the number of nuclei per cm³

N is the number of antiprotons (5×10^{11})

f_{rev} is the revolution frequency (43 kHz)

d is the target dimension in beam direction.

The calculated values are given in the last column of Table 1.

2. VACUUM

Reference 8 does not give gas flow values for the various pumping stages, but from the rather detailed description of their vacuum system we made the following estimates:

Stage	Pump	Pressure (Torr)	Gas flow (Torr l/sec)
Nozzle chamber	500 m ³ /h Roots	0.1	15
Collimator	1800 l/sec oil diffusion	10^{-3}	2
Reaction chamber	8000 l/sec oil diffusion	$< 10^{-5}$	$< 8 \times 10^{-2}$

The gas flow into the reaction chamber is, to our accuracy, just the beam flux, since due to the well defined beam edges there is practically no diffuse gas entering the chamber.

Although it might not represent the most economic solution, it seems that the vacuum system of the proposed polarized atomic beam target could easily be adapted to the condensed molecular beam.

Stage	Turbomolecular pumps (ℓ/sec)	Pressure at pump entry (Torr)
Nozzle chamber	3×3000	2×10^{-3}
Collimator 1	3000	7×10^{-4}
Collimator 2	3000	10^{-5}
Collimator 3	3000	10^{-7}

The main difference would be in the fore pump stages for the three nozzle chamber pumps. Each one will require a 250 m³/h Roots in order to ensure a fore vacuum below 0.1 Torr.

Some modifications are required for the beam dump, since with the high gas flow there might be a high backstreaming rate, we propose to introduce one differential pumping stage in the following way:

The cryopump is separated from the interaction region by a diaphragm with a small hole (~ 5 mm $\varnothing$). The direct beam would still be pumped by the central region of the cryopump, while the backstreaming gas and any diffuse contribution would be eliminated by the outer parts of the same pump. A 450 ℓ/sec turbomolecular pump is required for this stage to pump the $\sim 1\%$ He in the beam.

Although no detailed data are available, we assume that not more than one warm-up cycle per day will be necessary for the cryopump. During this time, a small "valve" would close the hole to the interaction region, and the hydrogen would be pumped away by the 450 ℓ/sec turbo.

With this system the pressure increment in the vicinity would not be more than a few 10^{-10} Torr.

Figures 3 and 4 show how the molecular beam system of Ref. 8 fits into the chamber of the polarized atomic beam target [following the guidelines of the SPS¹⁰⁾ this version uses only turbopumps with vertical rotation axis].

3. INTERFERENCE WITH THE SPS BEAM

With an average pressure of 10^{-9} Torr the integrated pressure in the SPS is 7×10^{-4} Torr·cm. Beam No. 4 from Table 1 corresponds to about 4 times this value. Beam blow-up by multiple scattering will still be small, and electrons created in the molecular beam can easily be removed by clearing electrodes since the volume is very small.

4. CONCLUSIONS

Condensed molecular beams can, with a minimum of interference, provide a gas target with a luminosity in the 10^{30} - 10^{31} region, using practically the same vacuum system as the polarized atomic beam. Even higher luminosities might be possible, since the curves in Ref. 8 show no saturation.

Generally speaking, a condensed molecular beam target would have the same interesting properties as the polarized atomic beam, i.e. very small volume, low background, very efficient use of the SPS beam and low interference with the accelerator.

Beams of similar luminosities per nucleon can be produced with complex nuclei, such as N_2 .

In a short time we would like to submit a Letter of Intent concerning the physics aspect of this project.

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Table 1

Beam characteristics and luminosity estimates (for $5 \times 10^{11} \bar{p}$)

Beam No.	Type	Intensity (atoms/cm ² sec)	Velocity (cm/sec)	Dimension (cm)	Density (atoms/cm ³)	Equ. pressure (Torr H ₂)	Flux (atoms/sec)	Equ. gas flow (Torr l/sec)	Luminosity (cm ⁻² sec ⁻¹)
1	Polarized proton	6×10^{17}	1.2×10^5	0.4	5×10^{12}	7×10^{-5}	7×10^{16}	10^{-3}	4×10^{28}
2	Supersonic room temperature	4×10^{17}	2.7×10^5	1	1.5×10^{12}	2×10^{-5}	3.2×10^{17}	5×10^{-3}	3×10^{28}
3	Condensed molecular	8×10^{18}	7×10^4	0.3	1.2×10^{14}	1.8×10^{-3}	5.6×10^{17}	8.6×10^{-3}	8×10^{29}
4	Condensed with He	5×10^{19}	7×10^4	0.3	7.2×10^{14}	10^{-2}	3.6×10^{18}	5×10^{-2}	5×10^{30}
5	FNAL			1.5	6×10^{16}	1			1.3×10^{33}

Figure captions

- Fig. 1 : Laval nozzle.
- Fig. 2 : Condensed and supersonic hydrogen molecular beam profile.
- Fig. 3 : Vacuum system with molecular beam.
- Fig. 4 : Vacuum system with atomic polarized beam.

Fig. 1

Abb. 6. Die Molekülstromdichte j von Wasserstoffstrahlen in Abhängigkeit von der Koordinate y des Auffängers senkrecht zur Strahlachse in 44 mm Entfernung vom Kollimator für die Düsentemperaturen $T_D = 293^\circ\text{K}$ und $T_D = 20,4^\circ\text{K}$. Der Einlaßdruck betrug 705 Torr bzw. 539 Torr.

Fig. 2