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How can we precisely deliver an ultra-low flow atomic beam into a cryogenic UHV environment?

At the AEGIS experiment at CERN's Antimatter Factory, millions of antiprotons are captured and cooled to subthermal temperatures in cryogenic (<10 K) Penning-Malmberg traps, consisting of segmented cylindrical electrodes (3 cm in diameter). This setup enables long-term storage of antimatter (up to several days at pressures below $1e-15$ mbar) for studies of antimatter-bound systems.

AEGIS aims to use these trapped antiprotons as targets for a subthermal or thermal atomic beam to investigate antiproton-atom interactions at ultra-low energies. As a proof of principle, isotopically pure krypton gas (boiling point 120 K) will be used.

One proposed approach is to inject krypton gas through a 40–50 cm long capillary. One end of the capillary is connected to a low-pressure reservoir (< $1e-6$ mbar at 300 K) via a valve, while the other end acts as a nozzle inside the cryogenic trap. The gas is directed radially through a hole in one of the trap electrodes, forming an atomic beam aimed at the trapped antiprotons.

To prevent freezing, the capillary must be heated above 120 K prior to injection. The injection itself occurs over a timescale of a few seconds. Ideally, the beam flow can be adjusted by tuning the reservoir pressure, enabling systematic studies.

This setup presents several technical challenges, including:

- How can we accurately estimate and control ultra-low flowrates, down to millions of atoms per second?
- How can we minimize heat load on the Penning-Malmberg trap during pre-injection heating of the capillary?
- How can we achieve a collimated atomic beam from the capillary nozzle (e.g., via a skimmer)?
- How can we minimize gas contamination in the trapping region after injection?

We are seeking ideas and expertise from vacuum engineering, materials science, microfabrication, cryogenic engineering, and related technical fields.