Positron accumlation and transportation for antihydrogen synthesis

Introduction

In last several years, we have been working hard towards the synthesis of antihydrogen in order to study the validity of the CPTsymmetry at CERN (European Organization for Nuclear Reserch).

The CPT symmetry is symmetry of physical laws under simultaneous transformations of charge, parity, and time. Generally, the CPT symmetry is supposed to be always preserved, because the CPT theorem states that any Lorentz invariant local quantum field theory with a Hermitian Hamiltonian must have this symmetry.

If the CPT symmetry holds, particles and antiparticles will have equal masses, lifetimes, spins, and exactly opposite charges and magnetic moments. Various measurements have been carried out to compare the properties of particle and antiparticle, like e^-—e^+, p—$\bar{p}$, μ^-—μ^+, but so far no symmetry violation has been observed.

Our goal is to test CPT symmetry by means of an accurate spectroscopy of antihydrogen atoms.

Recently, we have succeeded to accumlate tens of millions of antiprotons, which is two orders superior to the number other groups (ALPHA, ATRAP) have achieved to accumulate.

Acusp trap for trapping both antiprotons and positrons and synthesizing antihydrogen within has been also constructed. In the present study, we developed a positron accumulator, which is the last piece for realizing the synthesis of antihydrogen in the trap.

Method and Apparatus

Two methods have been widely used to accumulate positrons. One is the N_2 gas-buffer scheme, in which positrons lose their energy through excitation of the N_2 molecules. The other is the electron cooling scheme, in which the energy is lost through coulomb scattering with electrons. The former inevitably requires a buffer gas region where vacuum level is relatively poor. The latter can be operated in ultra high vacuum condition, but requires cryogenic temperature for its operation.

The trapping efficiency of the positron accumulator is defined as R_e/N_e, where R_e is the number of trapped positrons and N_e is the number of the positrons injected into the trap, both per second. There is a report of the efficiency of as high as 20% for the N_2 gas-buffer scheme whereas the maximum efficiency reported for the electron cooling scheme is around 1%.

In our experiment, the positrons are firstly trapped in their own accumulator, which is separated from the cusp trap by a gate valve. When ready, we open the valve and transport the positrons into the cusp trap.

This arrangement makes dealing of the problems related to the poor vacuum of gas buffer scheme manageable. Thus we decided to use the N_2 gas buffer scheme, which has higher trapping efficiency.

Our apparatus consists of a tungsten moderator, buffer gas region, and positron trapping region (fig. 1). The buffer gas region and the positron trapping region are separated by an aperture. The trapping potential for positron is given by a set of ring electrodes. Firstly positrons emitted from a ^{22}Na source (50mCi), whose kinetic energy ranges from 0 to 540keV are stopped in the tungsten moderator. The moderator has a negative work function for positrons, and reemits positrons with a monochromatic energy of around 3eV.

Then the reemitted positrons are decelerated in the N_2 buffer gas, and finally accumulated in the trapping region after further losing their energy with the collisions with residual gas.

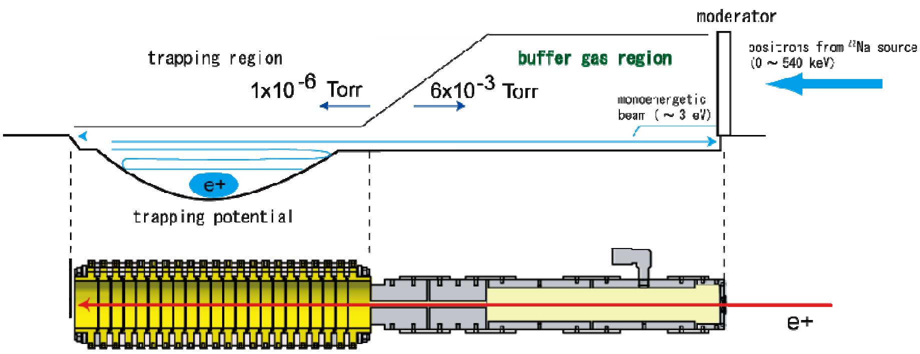

Fig. 1

Positron accumulation and transportation

In order to maximize the number of trapped positrons, we optimized parameters such as profile of trapping potential, buffer gas pressure, the potential energy of the moderator. We achieved the trapping efficiency of around 17%, assuming the moderator's efficiency to be 10^{-4}. We succeeded to accumulate 10^5 positrons in 10 seconds.

The efficiency of around 17% is comparable to other positron accumulators, like the one used in ATHENA. Currently the number of trapped positrons is partly limited by the life time of the positrons in the trapping region, which was around 30 seconds. We are considering the way to improving the vacuum level in the trap. Applying RF field to compress the positron cloud is another option under consideration. We are also working on the moderator system to obtain higher moderation efficiency.

After successful accumulation of positrons in the trap, we transported the positrons to the cusp trap. Figure 2 shows the transport line connecting between the positron trap and the cusp trap. Three solenoid coils make magnetic field which guide the extracted positrons to the cusp trap. The timing for switching the potential wall in the cusp trap was consistent to the value expected from the time-of-flight of the extracted positron beam in the transport line.

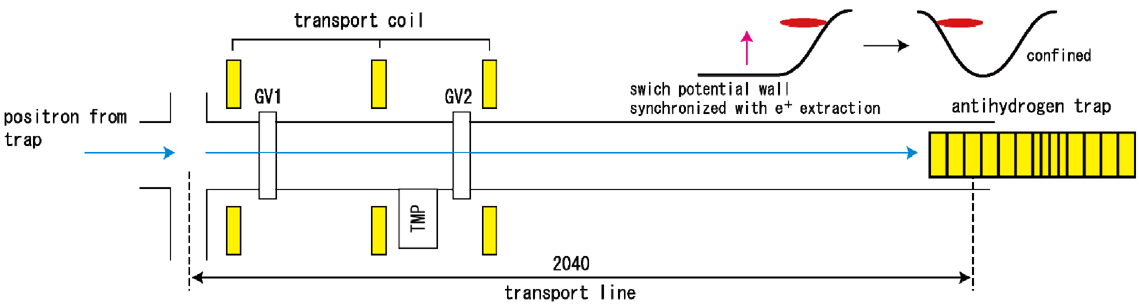

Fig. 2

Summary

We have successfully constructed a positron accumulation system using N_2 gas buffer scheme. The trapping efficiency of the system was around 17%. Using this system we were able to accumulate 10^5 positrons in 10 seconds. We also have demonstrated the transportation of the positron from the accumulator to the cusp trap. Further improvement work on the system is underway.

In a separate development, an antihydrogen detector system is being installed surrounding the cusp trap. We expect to detect the signature of the synthesis of antihydrogen atoms in very near future.