THE LOW ENERGY POSITRON STORAGE RING FOR POSITRONIUM GENERATION: STATUS AND DEVELOPMENTS

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Abstract

The project of Low Energy Particle Toroidal Accumulator (LEPTA) is dedicated to construction of a small positron storage ring with electron cooling of positrons circulating in the ring. The project has a few goals: to construct the LEPTA storage ring and to study its characteristics; to set up first experiments with Ps in flight; to study positron dynamics in the ring. Presently the magnetic and vacuum systems of the positron ring are constructed and tested. The positron injector is designed and under construction now. Test of the magnetic system with electron beam is in progress. Commissioning of the ring with circulating electron beam is scheduled by the end of the year.

1 INTRODUCTION

Positronium (Ps) - the bound state of an electron and its antiparticle the positron is an ideal test object for bound state QED: QCD effects and the weak interaction play no role at the present state of the accuracy. With positronium fluxes in vacuum one can perform new original setting up the experiments (so-called positronium-in-flight set-ups) [1]. Among experiments of this type are the following:

- comparison of electron (e^-) and positron (e^+) electric charges;
- the measurement of the orthopositronium lifetime and the parapositronium lifetime;
- the positronium spectrum;
- the search for exotic and rare decay channels of parapositronium: $Ps \to n\gamma, n > 2$;
- search for a light, neutral, short-lived boson, via which o-Ps annihilation can occur: o-Ps$\to$b + $\gamma \to 2\gamma$

Perhaps, the most intriguing problem in positronium physics is the search for the *"mirror Universe"*. The accuracy of the measurement of the positronium life time, the probability of decays with momentum conservation and charge invariant infringement (CPT violation), fine structure of the positronium spectrum, Lamb shift measurements can be much higher than in traditional methods.

The new approach to the experimental studies of Ps physics relates to the idea of antihydrogen generation [3]. Key point of this idea is an application of electron cooling of positrons, which immediately leads to generation of Ps in-flight. A development of this idea [4, 5] would allow the production of intense pencil beams of orthopositronium ($30 - 1.7\times10^4$ sec^{-1}).

Nowadays similar experiments with spectroscopy of antihydrogen atoms, stored in magnetic traps, are under development by several groups [2]. One should underline that these experiments and the proposed ones in [1] are complimentary, and information to be obtained in both types of experiment has independent importance. This paper briefly discusses the parameters of general systems of LEPTA installation (Fig 1, Table 1), current status of its design and construction.

2 LEPTA INSTALLATION

The LEPTA installation consists of low energy positron injector working in the pulsed mode of operation, positron storage ring and detector system for first experiments.

The positron injector consists of positron source on the base of β^+ - radioactive isotope ^{22}Na (pos. 1 in the Fig 1) and penning type trap (pos. 2, Fig 1) placed under potential of 10 kV relatively to the ground (the ring injection energy). The positrons from the isotope moderated using a layer of noble gas (neon) condensed onto the source cone arrangement are accelerated to energy of about 40 eV and through Vien filter are directed to the trap. In the trap the positrons are stored during about 100 seconds and after that extracted by pulse of electric field and are injected into the ring.

Single turn injection of the positron beam is provided with the magnetostatic septum and electric kicker (pos. 3 and 4, Fig. 1) placed inside the septum solenoid. The magnetostatic septum is used also for superposition and separation of the circulating positron and single turn electron beams.

The design of the LEPTA ring, the scheme of the positron beam injection and the electron and positron beam superposition and separation are described in [3-6]. The storage ring is equipped with the electron cooling system (including electron gun – pos.5 and collector pos. 6 in the Fig. 1), RF system, diagnostic tools for measurement of the circulating beam parameters (two pick-up stations in the cooling section – pos. 7 in the Fig. 1 and optical diagnostic device). In the future one plans to install a betatron yoke in the straight section of the ring to provide induction acceleration of the circulating beam.

Focusing system of the ring consists of a few solenoids connected together as a racetrack and surrounded by a common magnetic shielding. Stability of the circulating beam motion is provided with special helical quadrupole coil placed inside the cooling section solenoid.

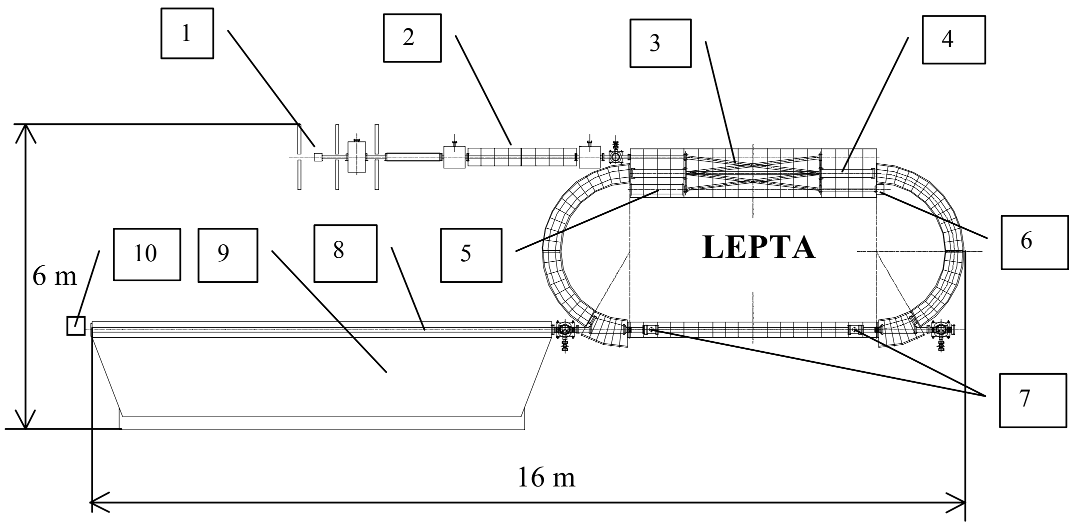

Fig 1. The LEPTA installation: 1 - positron source, 2 - positron trap, 3 - septum coils, 4 - kicker; 5 - electron gun, 6 - electron collector, 7 - pick-up stations, 8 - decay channel, 9 - dipole magnet, 10 - Ps detector

Table 1. General parameters of the LEPTA.

Circumference	m	17.12
Positron energy	keV	10.0
Revolution period	nsec	300
Longitudinal magnetic field	G	400
Major radius of the toroids	m	1.45
Bending magnetic field	G	1.75
Gradient of the spiral quadrupole field	G/cm	10.0
Positron beam radius	cm	0.5
Number of positrons	-	$1\cdot10^{9}$
Vacuum	Torr	$1\cdot10^{-10}$
Positron beam life time	sec	100
Electron cooling system		
Cooling section length	m	4.03
Beam current	A	0.5
Beam radius	cm	1
Characteristic cooling time	msec	100
Ortopositronium beam parameters		
Intensity	sec^{-1}	$1\cdot10^{4}$
Angular spread	mrad	1
Energy spread	-	$1\cdot10^{-3}$
Flux diameter at the ring exit	cm	1.1
Decay length	m	8.52

Vacuum chamber of the cooling section is insulated from the ground and some potential can be applied to it to introduce well-controlled velocity difference between circulating positron and cooling electron beams.

The experiments with the positronium flux will be performed with a coasting positron beam. The investigations of the circulating beam dynamics, friction force measurements and investigations of the electron-positron recombination process will be performed in the bunched mode of operation. RF system of the storage ring includes the $\lambda/4$ cavity loaded by capacity which is placed at the exit of the cooling section. The cavity works on the first harmonic of revolution frequency (about 3 MHz), maximum voltage amplitude is about 100 V.

The first experiment proposed with atoms-in-flight is the direct comparison of the electric charges of the particles forming these atoms measuring their displacement after crossing a transverse magnetic field [1]. The dipole magnet for this experiment (pos. 9, Fig 1) is proposed to have a length of 8.5 m and magnetic field strength of 2 T. A coordinate sensitive detector (pos. 10 - for instance, one can use an image detector based on multi-channel plate (MCP) amplifier combined with digital video camera) is placed at the exit of the magnet. Design of the detector is in progress now.

Design of the injection system was performed in collaboration with M.Charlton group and its nearest prototype is the positron trap of ATHENA project [2]. Positron source was constructed and it is under assembly now. Positron trap is under construction.

Vacuum chamber of the ring was constructed and tested. After the baking procedure the residual gas pressure of the order of 10^{-8} was obtained. This value was limited by pumping speed of used ionic pump, the outgasing from the chamber walls lies in the standard range for stainless steel.

General elements of the magnetic system were constructed and tested at the special test bench. For magnetic field measurements the nuclear magnetic resonance magnetometer [7] was used. The results of the field measurement showed, that with the correction coils the field homogeneity in the cooling section can be achieved better than $\Delta B/B \sim 5\cdot10^{-4}$. The field homogeneity in the toroidal solenoids is a few units of 10^{-3}. These values correspond to the design parameters.

The helical quadrupole and septum coils were constructed and assembled. Power supply unit for the kicker is tested now using modelling kicker plates. The electron gun of the cooling system is constructed and will be used for tuning of injection system and test of the helical quadrupole coil. The collector of the cooling system is designed and its construction will be started in nearest future.

3 ADJUSTMENT OF LEPTA GENERAL SYSTEMS

Before assembling of the LEPTA installation its general systems will be tested and tuned at separated test benches.

The low energy positron source will be operated initially with a few hundred of μCi radioactive source in order to optimise the noble gas moderator parameters and adjust the transportation of the low positrons to the trap. Measurements of the positron trap efficiency and optimisation of trapping conditions will be performed with modelling electron beam. Investigations of the positron injector elements will be performed in parallel with adjustment and assembly of the ring magnetic system.

The design of the septum coil and kicker plates is based on the resonance optics scheme. Adjustment of these devices will be performed using the optical analysis of the electron beam temperature. The optical analyser [10] will be used also for test of the helical quadrupole coil, which goal is to measure the linearity of the quadrupole field and influence of the coil fringe fields on the beam angular spread.

The investigation of the electron beam transportation at injection energy through the injection channel and magnetic system of the ring will be performed in the single turn mode of the ring assembly. For this purpose one of the toroidal solenoids will be turned over. In this case the ring will be disclosed. The measurement of the transverse temperature of the beam at the exit of this toroidal solenoid permits to estimate the beam parameter perturbations during single pass through the ring. By this way the parameters of the kicker pulse, the quadrupole and the toroidal fields will be adjusted to minimise the transverse temperature of the circulating beam.

Preparations for these works are in the final stage. The ring assembly and beginning of the operation with circulating electron beam are scheduled for the end of this year.

The positron injector operation at designed intensity and experiments with circulating positron beam can be started the next year.

4 FIRST EXPERIMENTS WITH CIRCULATING BEAM

In the very beginning of the LEPTA ring operation the following problems have to be experimentally investigated: dynamics of the circulating beam; measurements of the friction force components acting on the positrons inside electron beam, investigation of the equilibrium state after completion of the cooling process; measurements of the e^+e^- recombination rate.

Experimental investigations of the particle dynamics in LEPTA ring have additional interest. An electron storage rind with similar magnetic structure is proposed as the base of electron cooling system with circulating electron beam, which permits to cool down the ions at energy of several GeV [3-5]. The peculiarity of the particle dynamics in the focusing system with longitudinal magnetic field is the strong coupling between horizontal and vertical degrees of freedom. The particle dynamics simulation in the LEPTA ring performed with especially elaborated computer code [8] shows the resonance structure of the stability diagram similar to strong focusing rings. Measurements of the resonance width and power will be performed with circulating electron beam.

Essential peculiarity of the electron cooling of positrons is magnetisation of both interacting particles. This process will be investigated experimentally for the first time. Preliminary results of numerical calculations of the friction force acting on the positrons inside the cooling electron beam performed in terms of binary collisions are presented in [9]. They indicate some difference of this process from the electron cooling of ions.

The friction force measurements will be performed using voltage step method in the region of big relative velocities and by measurement of equilibrium between cooling and RF forces in the region of small relative velocities.

The dependence of the electron–positron recombination rate on the relative particle velocity will be measured with the bunched positron beam. In this case the positron beam energy is determined by the frequency of RF cavity and electron beam energy can be varied in a wide range with high precision.

The solution of the mentioned problems will give us a base for detail elaboration of the first physical experiments with positronium in-flight.

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