LOW ENERGY POSITRON STORAGE RING FOR POSITRONIUM GENERATION: STATUS AND DEVELOPMENT

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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. Such a peculiarity of the LEPTA enables it automatically to be a generator of positronium (Ps) atoms, which appear in recombination of positrons with cooling electrons inside the cooling section of the ring. The Ps atoms form an intense, up to 10^{+4} atoms/sec, flux which has very small angular, of order of 1 mrad, and momentum (less than 0.1%) spreads. The project has a few goals: to construct the LEPTA storage ring and to study its characteristics; to study particle dynamics in the ring; to set up first experiments with Ps in flight. At that time already the design of the storage ring and the elaboration of the technology of the ring elements manufacturing were done. The vacuum chamber of the ring was constructed and tested. Solenoid of electron cooling system was constructed, tested and adjusted. Other general elements of the magnetic system are under construction and will be delivered until the end of 2000. Injection system and detector for first experiments with positronium flux are under design.

1 INTRODUCTION

Positronium (Ps) is the bound state of an electron and its antiparticle the positron. Both components are structureless and pointlike leptons, thus avoiding the difficulties encountered with the proton structure in hydrogen. Ps is completely described by only two parameters: the Rydberg constant R_∞ and the fine structure constant α. QCD effects and the weak interaction play no role at the present state of the accuracy. For these reasons Ps is an ideal test object for bound state QED. With positronium fluxes in vacuum one can to perform new original setting up the experiments (so-called positronium-in-flight set-ups) without a distortion caused by medium in the traditional methods of the positronium generation in a target. 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 [1]. Positronium generation in flight presumes design and construction of positron injector of high intensity working in the pulsed mode of operation, positron storage ring equipped with electron cooling system, detector for first experiments. This paper briefly discusses the parameters of general systems of LEPTA installation (Fig 1), current status of its design and construction.

2 INJECTION SYSTEM

The positron injector has to provide the positron beam of the radius of 0.5 cm, at energy of 10 keV, at intensity of 10^8 – 10^9 particles per pulse and of the duration of 300 nsec or less. The injection periodicity is about 100 sec (this value corresponds to the positron beam life time in the storage ring). At the first stage of the LEPTA operation we plan to use a positron source on the base of $\beta+$ - radioactive isotope ^{22}Na (pos. 1 in the Fig 1). The encapsulated radioactive source of 10 - 20 mCi is placed on the coldhead capable of reaching 5.5 K. At the exit of the source capsule there is a cone shaped copper extension. The fast positrons from the source are emitted over a continuous range of energies up to a cutt-off energy of 545 keV. These are moderated using a layer of noble gas (neon) condensed onto the source cone arrangement. The efficiency of this type moderator lies in the range from 0.2 to 0.8%. The positron energy spread at the exit of moderator is about 2 - 5 eV. After moderation the slow positrons are accelerated to energy about 40 eV and through Vien filter are directed to the penning type trap (pos. 2 in the Fig 1). The flux intensity at the entrance of the trap is about 1-2*10^6 positrons per second. The source and beam transfer line are immersed into magnetic field of about 200 G produced by several separated coils.

The vacuum chamber of the trap consists of a pair of pumping boxes connected together by a cylindrical chamber. The cylindrical chamber is situated within the solenoid (field value is about 400 G) and contains an electrode array. This consists of a set of eight separated gold-plated aluminium electrodes with an appropriate potential applied to confine the positrons in the axial direction after the initial trapping. The geometry of the electrodes is designed to allow a pressure gradient to be developed along their length.

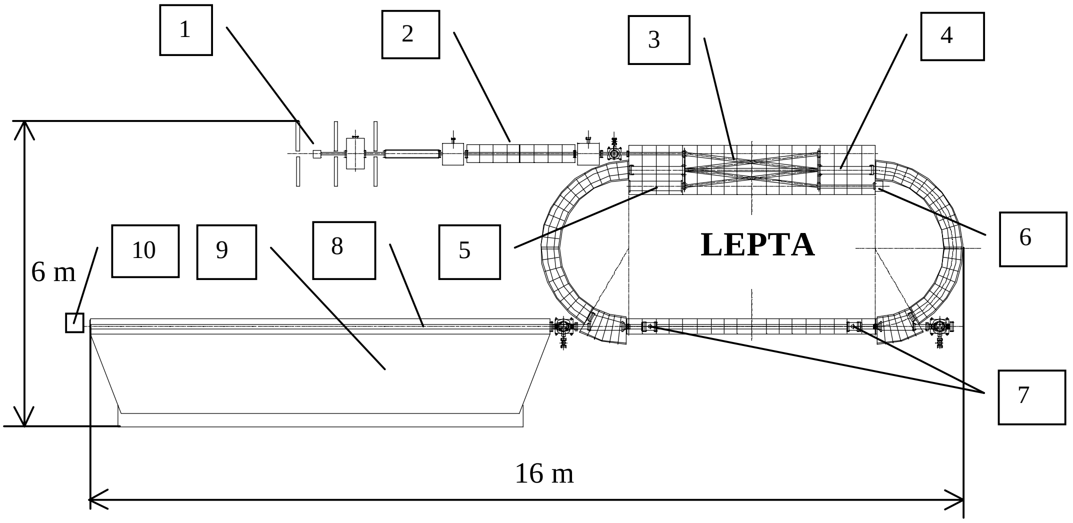

Fig 1. The LEPTA installation: 1 - positron source, 2 - positron trap, 3 - septum coils, 4 - kicker; 5 - electron gun, 6 - electron collector, 7 - pick-up stations, 8 - decay channel, 9 - dipole magnet, 10 - Ps detector

Positrons are stored in the trap for about 100 seconds and are thermalized in collisions with the buffer gas molecules (nitrogen) to room temperature The trapping efficiency is about 60% at optimum distributions of the buffer gas pressure and electrostatic potential along the trap. Positron source and vacuum chamber of the trap are placed at electrostatic potential of 10 keV (the ring injection energy) relatively to the ground. When the storage process is completed the positron bunch is extracted from the trap by pulse of electric field. Energy spread of positrons after extraction from the trap corresponds to the extracting potential difference along the positron bunch length and is about 2-5 eV. Positron current pulse duration at the trap exit is about 40 nsec. After extraction from the trap positrons are accelerated by electrostatic field up to injection energy (10 keV) and are injected into ring. Stability of accelerating field is about 10^{-4} and absolute value of positron energy spread after injection is less than 10 eV that corresponds to the ring dynamic aperture on momentum deviation [3]. The number of positrons injected into the ring after storing in the trap is about 10^8. Conceptual 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]. We plan to perform the complete of the technical design and construction of the trap in the next year.

3 LEPTA RING

The design of the LEPTA ring, the scheme of the positron beam injection and the electron and positron beam superposition and separation, positron storing in the ring are described in [3-6]. The ring (see in the Fig 1, and Table 1) has 2 toroidal solenoids and 2 straight ones, connected together as a racetrack and surrounded by a common magnetic shielding. Vacuum chamber is placed inside the solenoids. The vacuum chamber and solenoid of electron cooling section were constructed last year. For commissioning of the magnetic system elements a test bench was designed and constructed. For magnetic field measurements the nuclear magnetic resonance magnetometer [7] is used. The accuracy of the measurement of the magnetic field absolute value using this device is 10^{-5} in the range from 0.5 to 30 kG.

Table 1. General parameters of the LEPTA.

Circumference	m	18.12
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 quadropole 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	4.53
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

For positioning of the magnetometer sensor a special supporting bar and carrier moving with fixed step along the axis of the solenoid were designed and constructed. A power supply unit of current value up to 2.5 kA at relative current stability of 10^{-4} was used in the measurements. The results of the field measurement showed, that with the correction coils the field homogeneity in the cooling section can be achieved better than $\Delta B/B \sim 5{\cdot}10^{-4}$. This value corresponds to the design parameters. Other general elements of the magnetic system are under construction and will be delivered until the end of 2000. After field measurements and correction the ring assembly will be performed, section by section, with simultaneous assembly of the vacuum chamber and correction of the beam orbit using probe electron beam.

In 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 of the electron cooling of positrons, investigation of the equilibrium state after completion of the cooling process; measurements of the e^+e^- recombination rate. These problems solution will give us a base for detail elaboration of the first physical experiments with positronium in-flight.

The particle dynamics in LEPTA is calculated using especially elaborated computer code [8] and will be investigated with probe electron beam during the positron injector test and tuning. Numerical calculation of the friction force acting on the positrons inside the cooling electron beam is performed in terms of binary collisions and its preliminary results are presented in [9].

4 BEAM DIAGNOSTICS

The test of the electron gun of the cooling system is provided by the optical analysis of the electron beam temperature. The optical method will be used also for investigation of the electron beam transportation at injection energy through the injection channel. For this purpose one toroid magnet will be turned over. In this case ring will be disassembled. The optical analyser will be placed at the exit of this toroid. In this case the measurement of the transverse temperature of the beam 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 toroid fields will be adjusted to minimize the transverse temperature of the circulating beam. The optical analyzer is in operation now [10].

To measure the longitudinal momentum distribution of the positron beam during working cycle the Schottky diagnostic will be used. For Schottky diagnostic 2 pick-up stations will be installed (pos. 7 in the Fig. 1). They will be used also to measure the parameters of betatron oscillations and full current of the circulating beam. The diagnostics of circulating positron beam is under development now.

5 FIRST EXPERIMENTS WITH POSITRONIUM IN-FLIGHT

The first experiment which could be 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 (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. The position of the centre of mass of the positronium beam can be measured with accuracy of 0.02 - 0.1 mm. At the beam parameters listed in the Table 1 the accuracy of $\delta e/e \le 4{\cdot}10^{-10}$ can be achieved when the experiment duration is equal to about $4{\cdot}10^3$ seconds. The same experiment setting-up can be used for high precision measurement of o-Ps life time. However we do not need now the transverse magnetic field and the number of detectors is to be increased at least up to three. All these detectors are to be placed along drift chamber (pos. 8, Fig 1) shifted one from other by 3-5 m distance. Such a set-up allows to measure o-Ps decay rate along the base of the order of two decay lengths. The statistics precision of decay length λ determination has minimal value at $L = 0.68\lambda$, L is the base of measurement, and for big number of measurement points to have $\delta\lambda/\lambda \sim 10^{-5}$ one requires $\tau_{experiment} \sim 2{\cdot}10^7$ *sec ~ 1 year*, when the o-Ps flux is 10^4 sec^{-1}. It means, that an increase of o-Ps flux intensity is key point of this experiment.

The design of the detection system is in progress now.

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