PROJECT OF OBTAINING LONGITUDINALLY-POLARIZED COLLIDING BEAMS IN THE STORAGE RING VEPP-4 AT ENERGIES UP TO 2 x 2 GeV

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Summary

A project is developed to obtain longitudinally-polarized colliding electron-positron beams at the storage ring VEPP-4 using a superconducting solenoid which rotates a spin by the angle of 180° around the velocity vector ("Siberian snake" of the first kind). Particle polarization occurs in the booster storage ring VEPP-3 having a comparatively small time of polarization. The lifetime of longitudinal polarization is determined by quantum energy fluctuations and may constitute a few hours at energies of $\leq$ 2 GeV. The possibilities of increasing the luminosity at these energies are pointed.

General Description

A possible way of obtaining a longitudinal polarization in the experimental straight section of the electron-positron storage ring VEPP-4 is to place a solenoid, at energies of colliding beams up to 2 x 2 GeV, rotating the spin by the angle $\varphi = \pi$, in the opposite (technical) straight section (see Fig. 1). In this case, the stable direction of polarization, $\vec{n}(\theta) = \vec{n}(\theta + 2\pi)$ [1], lies completely in the orbit plane and makes an angle with the velocity vector equal to $\nu(\pi - \theta)$, where the azimuth is $\theta = 0$ at the location of solenoid (ν = E [MeV] /440.65).

The kinematic principle of this scheme has been suggested in[2,3] and the latter has been referred to as a 'Siberian snake'. It possesses a remarkable property: whatever the particle energy, the spin precession frequency around $\vec{n}$ is always equal to 1/2 in it and the vector $\vec{n}$ is oriented along velocity at the azimuth $\theta = \pi$ (the interaction point).

The papers /5,6/ demonstrate the possibility of using this scheme in real conditions of storage ring VEPP-4. The suggested version envisages the location of a superconducting solenoid with a maximum field integral of about 210 kGs·m in the technical straight section of VEPP-4 near the point of beam injection. The special lenses, whose purpose it to compensate the perturbation caused by the solenoid in the orbital motion, are placed next to this point.

The possibility of obtaining longitudinally-polarized particles in such a simple scheme is due to the fact that the booster storage ring VEPP-3, which has a short time of radiative polarization at the ejection energy ($\sim$ 20 min at E = 2,1 GeV), serves as an injector for the VEPP-4. Ejection of the polarized electrons (positrons)

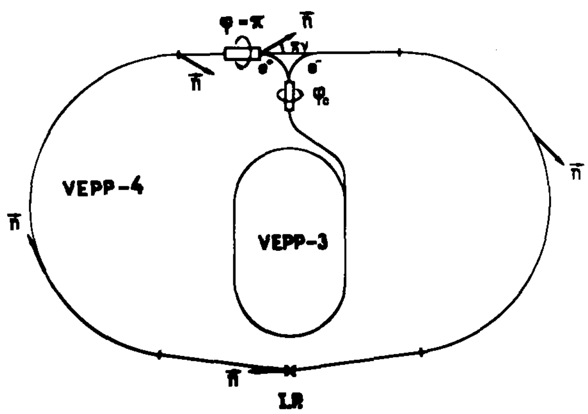


Fig. 1.

from VEPP-3 into VEPP-4 will occur when the solenoid is switched on. To ensure a high degree of longitudinal polarization, it is necessary to have as large magnitude of the projection of the spin vector of injected particles onto the vector $\vec{n}$ at the injection point as possible. In view of this, provision is made to control the beam polarization at the exit of the injection channel by means of a pulse solenoid mounted in it.

The time of existence of the longitudinal polarization is completely determined by a depolarizing influence of the quantum fluctuations of energy radiation. Since the polarization vector lies perpendicularly to the guiding field in the orbit plane, the mixing of the particle trajectories in the beam on account of these fluctuations results in a considerable spin diffusion destroying the initial polarization. The time of depolarization decreases rapidly with energy ($\sim E^{-7}$). However, at the VEPP-4 storage ring with an energy $\leq$ 2 GeV this time exceeds 1 hour. This is sufficient to make experiments with the longitudinally-polarized beams.

Polarization Control in the Injection Channel

The elements of the injection channel are not in a plane and, therefore, the spin rotations do not commute in it and the polarization vector in the VEPP-4 can take different directions, depending upon the beam energy E.

In the scheme described above the initial degree of longitudinal polarization equals

$\xi(\vec{S}\vec{n})$ where $(\vec{S}\cdot\vec{n})$ is the projection of the spin vector of injected particles onto the vector $\vec{n}$ at the injection point and ξ is the degree of transverse polarization of the beam in the VEPP-3 before its extraction ($max\ \xi = 0.92$). As seen in Fig. 1, the vector $\vec{n}$ lies in the median plane at the injection point and makes an angle $\pi\nu$ with the particle velocity vector.

With the aim of increasing the projection $(\vec{S}\vec{n})$, the polarization control will be made by a pulse 6-m-long solenoid with a field of up to 25 kGs. This solenoid will be located in front of the last element of the channel - a 90° bending magnet (see Fig. 1).

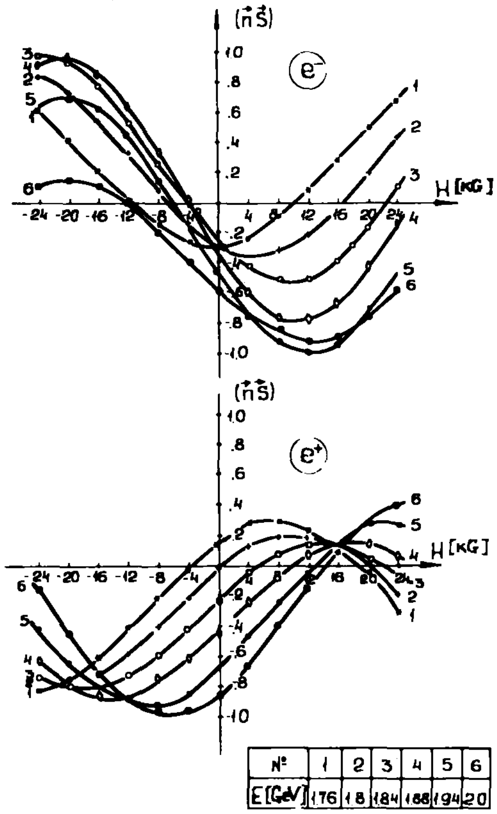
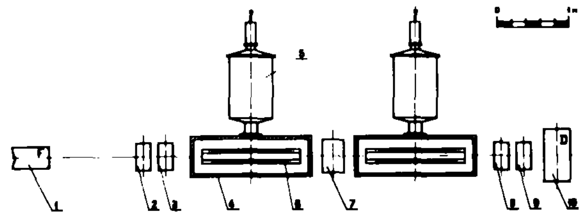


Fig. 2.

At a fixed injection energy E, the choice of the angle of spin rotation φ_c in the solenoid within the range $\pi/4$ to $\pi/2$ offers the possibility of obtaining the projection $(\vec{S}\vec{n}) \simeq 1$ for both the electrons and positrons. Fig. 2 presents the calculated dependence of the projection $(\vec{S}\cdot\vec{n})$ on various values of the solenoid field H and on the injection energy E. As is clear from the figure, the change of the sign of field H permits one to change the direction of electron polarization and, hence, to prepare any combinations of the helicities of colliding beams.

Solenoid at the VEPP-4

While rotating the spin by an angle of 180°, the solenoid in the VEPP-4 rotates simultaneously the plane of transverse oscillations (X-radial and Z-vertical) by a 90° angle and hence, strongly perturbs the orbital motion. Nevertheless, it is possible to compensate this perturbation by coupling the solenoid or a group of solenoids with quadrupole lenses rotated by definite angles[4,5,7]. On the basis of the scheme[7] an insertion into the storage ring has been designed, comprising two identical superconducting solenoids with the total angle of spin rotation π and five quadrupole lenses, four of which are rotated by an angle of $\pi/4$ (see Fig. 3 and Table I).



1.10 - elements of the main magnetic structure
2,3,8,9 - skew quads
4 - magnetic screen
5 - helium resorvoir
6 - superconducting solenoid
7 - quad

Fig. 3.

Table 1

Energy	1.98 GeV
Effective length of solenoids	2x145 cm
Effective field of solenoids	71.7 kG
Gradient x length (lens No 7)	$-2.76\frac{kG}{cm}$ x 36 cm
Gradient x length (lenses No 2 and No 9)	$\pm 2,26\frac{kG}{cm}$ x 24 cm
Gradient x length (lenses No 3 and No 8)	$\pm 2,01\frac{kG}{cm}$ x 24 cm
Total length of the insertion incl. the solenoid and lenses	532 cm

At the region of this insertion a matrix (X,X',Z,Z') of the phase-space transformation is equivalent to that of the empty gap with a length equal to the insertion length. A small difference consists in the availability of an additional phase shift by π between the vertical and radial betatron oscillations. The coupling between X- and Z-oscillations is localized at the insertion region because the radial betatron oscillations excited by quantum fluctuations in the ring, go over into the vertical deviations only inside the insertion. In this case, there is no excitation of the vertical phase volume out of the indicated section because of the absence of synchrotron radiation in it.

Depolarization Rate

According to Ref. /8/, the general expression for a characteristic depolarization time is of the form

$$\tau_d=\tau_o\langle|\mathcal{K}|^3\rangle\langle|\mathcal{K}|^3[1-\frac{2}{9}(\vec{n}\,\vec{v})^2+\frac{11}{18}|\vec{d}|^2]\rangle^{-1}$$

where $\mathcal{K}$ is the dimensionless curvature of an orbit in units of the inverse mean radius of the storage ring, $\vec{v}$ is the velocity (the velocity of light equals 1); the angle-shaped brackets stand for the averaging over the storage ring azimuth and $\vec{d}(\theta)$ is the function of spin-orbit coupling. The quantity τ_o is equal to the time of radiative polarization in the storage ring without solenoids. The first two terms in the brackets in the above expression take into account a direct depolarizing action of synchrotron radiation on the spin (spin-flip radiation). The last term is connected with a depolarizing influence of the quantum energy fluctuations in the presence of the spin-orbit coupling.

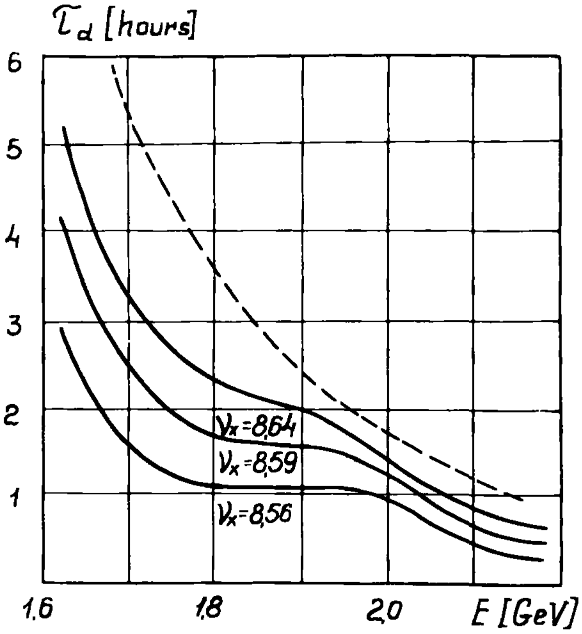


Fig. 4.

$\vec{d}(\theta)$ [8,9] The spin-orbit coupling function characterizes the response to the energy perturbations of a particle on the azimuth θ in the spin motion. In the present scheme the spin-orbit coupling makes a main contribution to the rate of spin diffusion.

Fig. 4 shows the calculated results[5,6] on the depolarization time as a function of energy. The dashed line shows the dependence $\tau_d(E)$ taking into account the variation of the closed orbit of particle due to quantum energy fluctuations. The solid lines correspond to the total dependence $\tau_d(E)$ with allowance for the changes and of the betatron motion as a result of energy fluctuations at different values of the frequency ν_x of radial oscillations. It is clear from the figure that at the ψ'-resonance energy (about 1.84 GeV), τ_d constitutes about 2 hours when tuning off a frequency by 0.1 from the half-integral spin resonance (in the operating region of betatron frequencies of the VEPP-4).

Luminosity

The method described above will enable one to obtain the longitudinally-polarized colliding beams at the VEPP-4 and make physical experiments with these beams at the energies $\lesssim$ 2 GeV, for example, in the region of ψ-resonances or that higher than the threshold energy of τ-lepton production (1.78 GeV).

At present, we consider the possibilities of increasing the luminosity of the machine by more than one order of magnitude at these energies (the current luminosity is about $3\cdot10^{28}$ $cm^{-2}s^{-1}$):

1) rearrangement of the optics of the experimental straight section in order to achieve $\beta_z^*\approx 5$ cm (instead of β_z^* = 45 cm);

2) using a wiggler with the aim of an incoherent increase of the phase beam volume;

3) application of the multibunch mode of operation (up to nine bunches in each beam).

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