# LONGITUDINALLY POLARIZED COLLIDING BEAMS

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The feasibility of experiments with the polarized colliding beams expands significantly possibilities of getting information on fundamental interactions. Even the use of the transversely polarized beams enables getting the more reliable and clear definition of spins for the intermediate states and final particles,[1,2] as well as to introduce the precise absolute energy scale.[3-5] But only the use of the longitudinally polarized colliding beams with particles of certain helicities, enables one to get basically new information. This circumstance forced us, in Novosibirsk, commencing from 1969, to develop the principles and structures of the storage rings which provide at a given azimuth the stability of any spin direction needed, including longitudinal direction[6,7] (see also Refs. 8 and 9).

1. In the storage ring of "conventional" type which magnetic field along the equilibrium closed orbit has a constant, for example, vertical z-direction (the field sign can vary) the spin orientation conserved from turn to turn is z-direction. In other words, when particles are moving along the equilibrium orbit their spins precess around this direction and the spin projection on this direction is constant. For example, if initially the particle spin has z-projection $+\frac{1}{2}$, this value does not change with time (of course, unless either dissipative or diffusional processes will affect). The projection $-\frac{1}{2}$ will be conserved just the same way. This statement is valid if the precession frequency (because of anomalous part of a particle magnetic moment) is not resonant to the frequency of orbital rotation along the equilibrium orbit.

The similar situation became valid also for the case of the storage ring with arbitrary oriented magnetic fields.[6,7] Namely, along any closed orbit there always is such a unit vector $\vec{n}_0(\theta)$, the projection on which of the spins of particles moving along this orbit has a constant value. In particular, if the particle spin is oriented along $\vec{n}_0(\theta_0)$ at some initial azimuth $\theta_0$, this spin will be oriented along (different in direction) $\vec{n}_0(\theta)$ at any other azimuth $\theta$ at any turn.

Selecting the shape of closed orbit which curve at any azimuth unambiguously determine the transverse magnetic field value for this azimuth and (or) introducing the azimuthal distribution of the longitudinal magnetic field one can achieve the required orientation $\vec{n}_0$ for the necessary azimuth; this orientation is the same at the sections with zeroth magnetic field on the closed orbit. In particular, one can achieve the longitudinal orientation $\vec{n}_0$ at the storage ring sections where colliding beam interactions are occurred. In this case, if the means are made polarized one can obtain interaction of particles with certain helicities. Varying the polarization sign for one or both beams one can consequently vary helicities of interacting particles.

Let us note that for studying, for example, the interactions which do not conserve the spacial parity, in principle, it is enough to have even one of interacting beams polarized (with the controllable level of polarization). Though, of course, experiments can be performed with better purity if there is a possibility to control the polarization in its sign and level for both beams.

2. Having in mind the possibility to achieve the desired behavior of the spin along the equilibrium orbit the first question is to find the spin motion while the particle motion deviates from the equilibrium one, i.e. in the presence of energy and betatron oscillations in the beam. This problem is "dynamic" part of the general question of conservation of the beam polarization level in a storage ring.

The particle motion with deviation of their orbital motion $\vec{R}(t)$, determined by initial conditions, from the equilibrium motion described by $\vec{R}_0[\theta(t)]$ can be presented by

$$\vec{r}[\theta(t),t] = \vec{R}(t) - \vec{R}_0[\theta(t)] \quad ;$$

similarly, the particle momentum deviation $\vec{P}(t)$ from the equilibrium $\vec{P}_o[\theta(t)]$ can be written down as

$$\vec{P}[\theta(t),t] = \vec{P}(t) - \vec{P}_o[\theta(t)] \quad .$$

The total spin motion can be described as a precession around the unit vector $\vec{n}(\theta,\vec{\tau},\vec{p})$ with the conserving in time of spin projection value onto this vector.[10-12]

The variation of $\vec{n}$ at small deviations of $\vec{\tau}$ and $\vec{p}$ is large in the vicinity of the precession frequency resonances with the combined frequencies of orbital motion (spin resonances) and decreases with the shifting from these resonances.

For the stationary energy deviations in the absence of betatron oscillations this follows directly from the general statement for closed orbits. In the case of betatron and energy oscillations the vector $\vec{n}(\theta,\vec{\tau},\vec{p})$ can be determined with the steep transition from the equilibrium motion to the given one. This can be done, for example, by introducing the condition that the spin oriented along $\vec{n}(\theta,\vec{\tau},\vec{p})$ at some moment of time will tend to some vector when in a certain number of turns the values $\vec{\tau}$ and $\vec{p}$ at the same azimuth $\theta$ will be close to initial ones.

All mentioned above can be presented in terms of formulae. Let us consider a particle with the charge e, mass m, spin s and magnetic momentum $\mu$. The vector $\vec{\mu}$ is related to $\vec{S}$ by the equation

$$\vec{\mu} = g\vec{S}$$

where $g = g_o + g_A$ is the particle gyromagnetic ratio, $g_A$ is its anomalous part ($g_o = e/mc$).

Then, at every given moment t the spin precession is described by the equation:[13]

$$\frac{d\vec{S}}{dt} = \vec{W} \times \vec{S} \quad ,$$

where for the particle, moving in magnetic field with the component $\vec{H}_\perp$ transverse to the particle velocity $\vec{v}$ and longitudinal component $\vec{H}_v$, the value $\vec{W}$ at the particle location point will be equal to

$$\vec{W} = -\left(\frac{g_o}{\gamma} + g_A\right)\vec{H}_\perp - \frac{g}{\gamma}\vec{H}_v \quad .$$

For motion along the closed orbit $\vec{W} = \vec{W}_o(\theta)$. In this case, $\vec{n}_o(\theta)$ is determined as a periodical solution (eigenvector) of the equation

$$\frac{d\vec{n}_o(\theta)}{d\theta} = \frac{\vec{W}_o(\theta) \times \vec{n}_o(\theta)}{\omega_o} \quad .$$

For this closed orbit the precession frequency will be the eigenvalue of the spin rotation matrix for one turn.

The slowly varying energy deviations $\varepsilon$ will lead to "shaking" of $\vec{n}$ which depend on $\varepsilon$ (appearance of the "spin chromaticity"); $\vec{n}(\varepsilon,\theta)$ can be found out similarly to the previous with an account of total dependence of $\vec{W}$ on $\varepsilon$ including the field variations on the deviated orbit corresponding to $\varepsilon$. This can be done according to the perturbation theory if one takes

$$\vec{W}(\varepsilon,\theta) = \vec{W}_o(\theta) + \vec{w}(\varepsilon,\theta) \quad , \quad \omega = \omega_o + \Delta\omega(\varepsilon) \quad .$$

Similarly, with the presence of betatron oscillations the deviations of field (on the particle orbit) from their values on the equilibrium orbit can be described by introducing the perturbation $\vec{w}$, which depends on the phase and amplitude of betatron oscillations with an account of the dependence on the same variables in $\Delta\omega$. The calculations of such a kind confirm that already said: deviations of the spin precession axis from the equilibrium (closed) spin trajectory $\vec{n}_o(\theta)$ rise with the particle precession frequency nearing the integral number combinations of the orbital motion frequencies. One should also take into account that even for the equilibrium orbit of the precession frequency is far from resonances, for particles deflected from the equilibrium motion such resonances can occur.

3. The behavior of the averaged polarization of the beam particles injected into a storage ring being initially polarized along $\vec{n}_o(\theta)$, will strongly depend on the certain situation. If the storage ring has neither orbital nor spin damping and diffusions, the established polarization level can be found out by the appropriate averaging over the phase volume of the coasting beam. If there are damping and diffusion, one should make the comparison between the resulting diffusion spin rate and the spin damping rate. In this case, the initially injected beam can be polarized. If the spin damping is low or there is no damping at all, one can find out the decrement of the beam polarization level with time affected by the spin diffusion.

The <u>spin damping</u> in a storage ring (with no loss in the beam intensity) can be done sufficiently effective but still only for electrons and positrons by using the spin effects at $e^{\pm}$ radiation in the external electromagnetic fields.[12,14] The spin diffusion can occur either as a direct result of the spin overturns during interactions between particles and quanta and other particles, or as a consequence of orbital diffusion in a beam under influence of various factors. As a rule, the strongest (needed most care to overcome its influence) is the diffusion of a second type where the spin and orbital motions are closely interrelated. In this case, the orbital diffusion causes the corresponding trembling of precession axis[15,16] leading with time to lowering the beam polarization level.

The orbital diffusion depending on its nature can variously affect the spin diffusion rate. The orbital diffusion can occur by jumps due to quantized losses on synchrotron radiation or scattering. The combined action of such jumps and the orbital friction form the equilibrium orbital beam characteristics and simulataneously determine the spin diffsuion rate which is the higher the stronger are deviation of $\vec{n}$ from $\vec{n}_0$ within the equilibrium beam emittance, and the deviations are the larger the closer and stronger are the spin resonances. In this case, as a rule, the spin resonances proceed rapidly and nonadiabatically.

With a weak orbital diffusion, caused by the stochastization of orbital motion with the combined action of many orbital resonances, the spin resonances can proceed slowly, with the total but reversible spin overturn while intersecting, and the spin diffusion resulting rate should be evaluated more specifically.

A special case for obtaining polarized beams in a storage ring is the "knock-out" of particles mainly with undesired polarization from the initial nonpolarized beam. The polarization resulting level is determined by the relation of the particle loss probability for particles with desired and undesired polarity and of the agreeable intensity loss, and also by the spin diffusion resulting rate.

As the examples should serve the proposals to obtain on storage rings the $e^{\pm}$ beams by "knocking-out" due to the inverse Compton effect with longitudinally polarized photons in the section with longitudinal $\vec{n}_0$ and[19] $\bar{p}$ beams polarization using the difference of the total cross sections of nuclear interaction for opposite orientations of spin $\bar{p}$ at interaction with the superfine polarized target;[20,21] in this case, it is more profitable to use the storage ring section with stable longitudinal $\bar{p}$ polarization and similarly polarized p of the atomic hydrogen beam.

4. With an account of all mentioned above let us consider some versions of longitudinally polarized electron-positron colliding beams.

First, let us assume that in the storage ring under consideration (until it has no special insertion for getting the longitudinal polarization) the equilibrium level of radiative polarization is sufficiently high and the equilibrium polarization direction is vertical. Now let us install into one of straight sections the insertion (Fig. 1) incorporated such sections with radial magnetic field which enable the vertical polarization in the ring part to transform at the collision point into the longitudinal polarization. If the $H_x$ distribution in the section is antisymmetric with respect to collision point, the equilibrium orbit outer of the insertion will be restored. If, in this case, there is no lenses through the whole section with the $H_x$ fields introduced, $\vec{n}$ in the main part of circumference will not also be disturbed.

As a rule, though at the collision section (a,b) the arrangement of a small β-function is needed. To this end it is required to install quadrupole lenses on this section. In this case, for preservation of $\vec{n}$ perturbation on the main part of a storage ring, it is necessary to have zeroth vertical dispersion on the main part of storage ring even after introducing the special section and the particles vertically polarized at the section input should be similarly polarized at the output even in the presence of energy deviations and betatron oscillations. This corresponds to satisfying some conditions:

$$\psi_z(0) = \psi_z(\ell) = 0 \;;$$

$$f_x'(a) = f_x'(b) - (2\ \text{conditions}) \quad .$$

Satisfying these conditions will provide the spin diffusion conservation on the main part of circumference at the same level as before introducing the special section. An additional

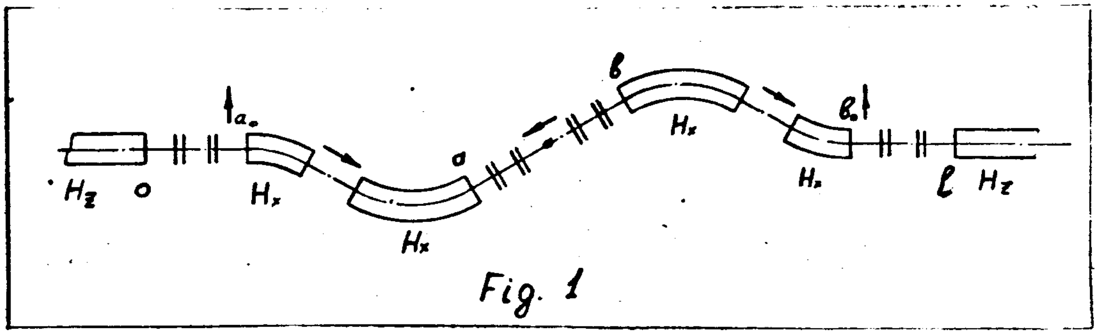


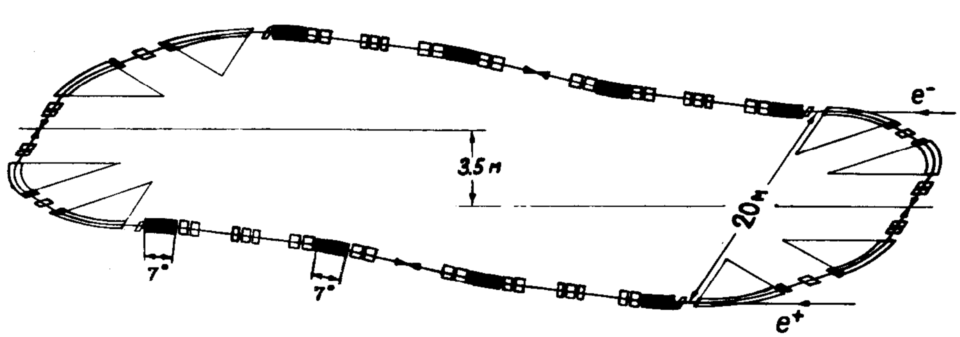

Fig. 1.

diffusion introduced by radiation in the section itself is small and it is only connected with radiation processes in the field $H_x$; consequently, the $H_x$ fields should not be excessively high compared to the storage ring fields. The contribution of the section into the spin friction is zeroth in the case.

The schemes of the type considered seem to be promising for producing longitudinally polarized beams in storage rings at an energy above 10 GeV. The $H_x$ field required do not vary with an energy increase (for the electron spin rotation from the vertical to longitudinal direction it is needed $H_x \ell = 26$ kGs·m) and the orbit vertical distortions decrease inversely proportional to energy.

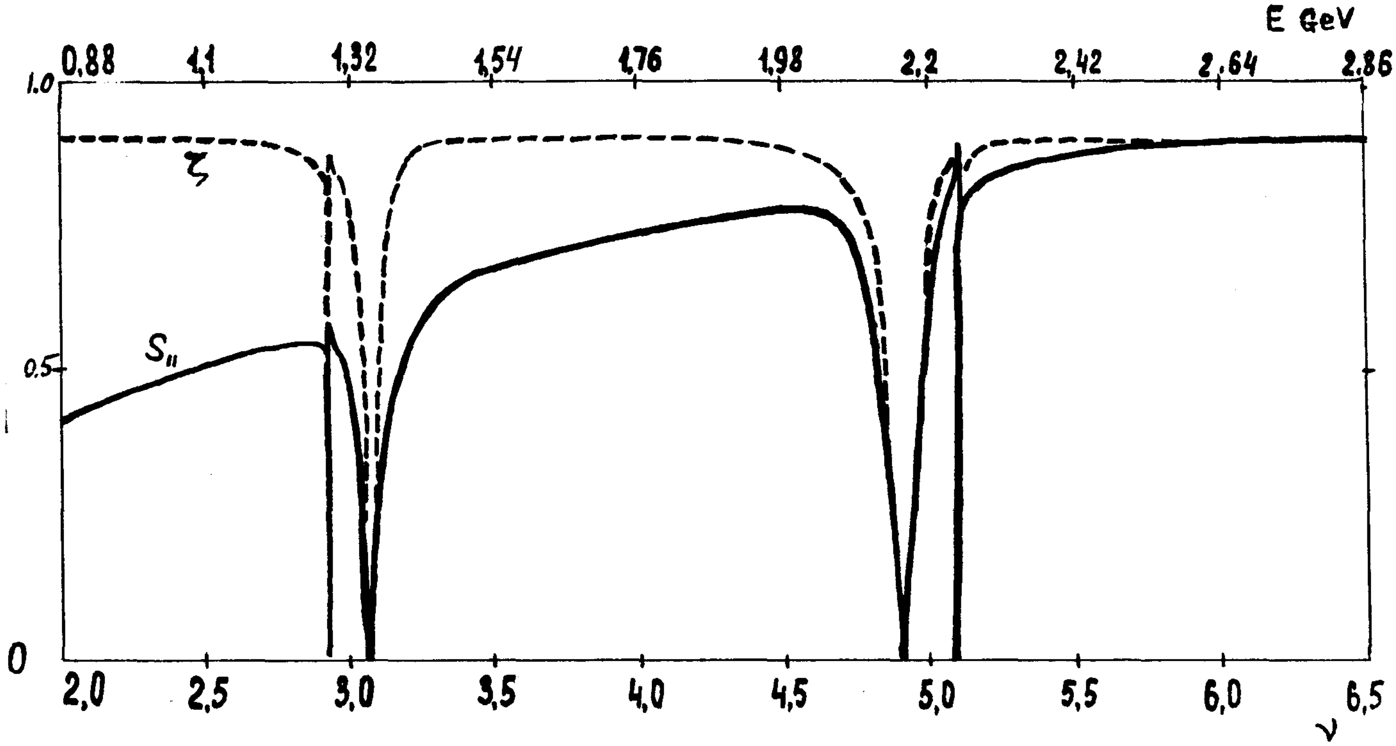
5. For producing longitudinally polarized beams at an energy range $\sqrt{s} = 1.5 \div 5$ GeV with an acceptable way a special structure of the "two-level" storage ring (Fig. 2) has been developed. The structure of sections for transition between $H_z$-magnets located at different levels should satisfy the conditions similar to those given in point 4. The scheme given in Fig. 2 was adopted as an optimum for obtaining simultaneously the high level of equilibrium longitudinal polarization and high luminosity. The polarization level as a function of energy at a certain given geometry is given in Fig. 3.

6. At moderate energies the schemes look quite attractive where for equilibrium polarization control the sections with longitudinal magnetic field are used (the required $H_v$ = 100 $E_{GeV}$ kGs m are reasonable to be obtained with the superconductive solenoids). Two




Lay-out of the $e^+e^-$ storage ring with two inclined straight sections for experiments using longitudinally polarized beams in the energy range from 2x0.7 up to 2x2.5 GeV.

Fig. 2.




Polarization vs. energy.

Fig. 3.

schemes of such a kind are quantitatively considered for the VEPP-4 storage ring.[22]

The first scheme designed for producing longitudinal polarization in the region of the resonances is given in Fig. 4. Radiative polarization in the field of the main storage ring is used. Its rate might be made higher using the $H^3$-snakes. In the beginning of the experimental section the vertical polarization is transformed into the radial one with longitudinal magnetic field and subsequent vertical fields complete the spin rotation to the longitudinal direction. Upon passing the collision point all the actions with spin are performed in the opposite order resulting in that the spin (more precisely - magnetic moment) of the equilibrium particle turns out to be oriented along the storage ring magnetic field. As a final bending magnetic field in the collision point region one can use the magnetic spectrometer MD-1 (Fig. 4) field.

Let us note two moments.

The sections with longitudinal magnetic field couple the orbital x- and z-motions. In order to avoid this parasitic effect both at the main part of storage ring and collision point the solenoids should be combined with the skew-quadrupoles.[22]

The finally bending magnets should not be too large in order to prevent radiation fluctuations in them (at these sections the spin chromaticity is large) not too much enlarged the spin diffusion and hence not to decrease the equilibrium polarization level. Figure 5 represents the equilibrium polarization degree $\zeta$ as a function of energy for one of versions of the experimental section structure.

7. Completely different version turned out to be promising for producing longitudinal polarization on VEPP-4 at low energies down to 2 GeV. The spin diffusion due to synchrotron radiation in this case is rather weak and particle polarization can be achieved due to initial radiative polarization in a booster storage ring VEPP-3 which radius is smaller and therefore polarization time at an energy 2 GeV turns out to be of the order of half an hour.

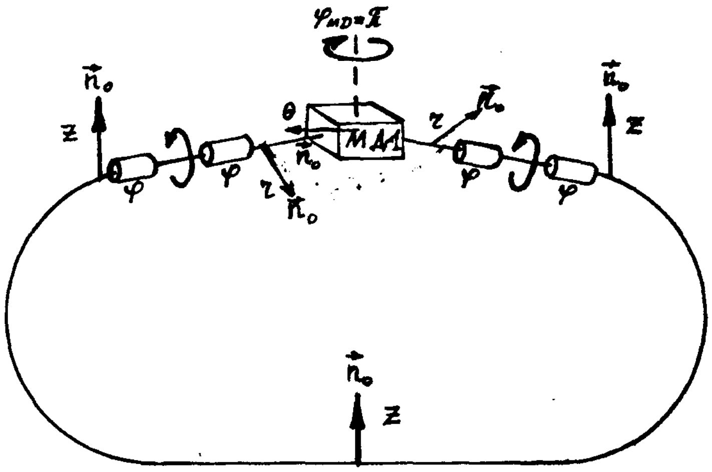



Fig. 4.

The longitudity of the equilibrium polarization of beams at the collision point is achieved due to the section with the longitudinal magnetic field rotating the spin at an angle $\pi$ around the velocity direction and occurred exactly in half a turn (along the phase of orbital and correspondingly spin motion).[23] The storage ring structure and behavior of the spin closed trajectory is shown in Fig. 6. The main contribution into depolarization rate is put by the storage ring bending section where $\vec{n}_0$ lies in the orbit plane and the energy jumps because of quantization of synchrotron radiation make the maximum contribution into the spin diffusion. The depolarization rate behavior as a function of energy is given in Fig. 7.[23]

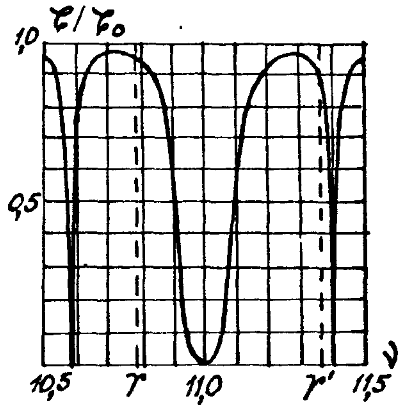



Fig. 5.

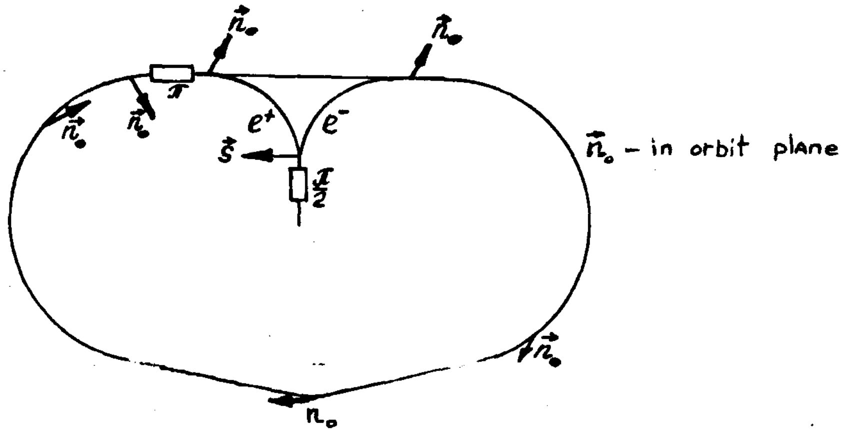
Let us note that in the case under consideration the spin precession frequency is equal to 1/2 for all energies and it is sufficient to achieve the absence of resonance effects at any energy.

The spin of injecting particles should be directed along $\vec{n}_0$ at the injection point; orientation adjustment of the injecting particle spin is accomplished with placing the solenoids at the appropriate sections of injection channels of VEPP-3 - VEPP-4.

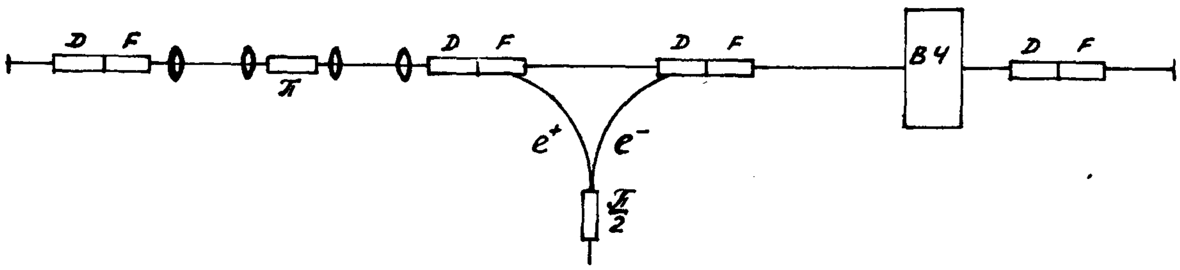
8. In the experiments with the proton and antiproton colliding beams at high energies it is impossible (yet) to use any kind of polarization method during the experimental run; particles should be injected already polarized. The optimal method for producing the intense proton (deuteron) beams is their charge exchange stacking with the use of $H^-$ beams with polarized protons, and for producing polarized antiprotons one should apparently use the "knock-out" method (see point 3).

The maintenance of $p^{\pm}$ beam polarization while their acceleration in the storage ring during the experimental run is the problem which is ever complicated with an energy growth. At energies above tens of GeV one should use the pairs of $\pi$-snakes[24] rotating the spins around various axes (longitudinal and radial). The $\pi$-snakes, however, are also needed for $e^{\pm}$ storage rings at energies of a few tens of GeV and higher ($\pi$-snakes = "Siberian snakes").

The use of special sections performing longitudinal orientation of $\vec{n}_0$ at the collision sections with fulfillment of conditions similar to those given in point 4 does not make in practice additional spin diffusion.

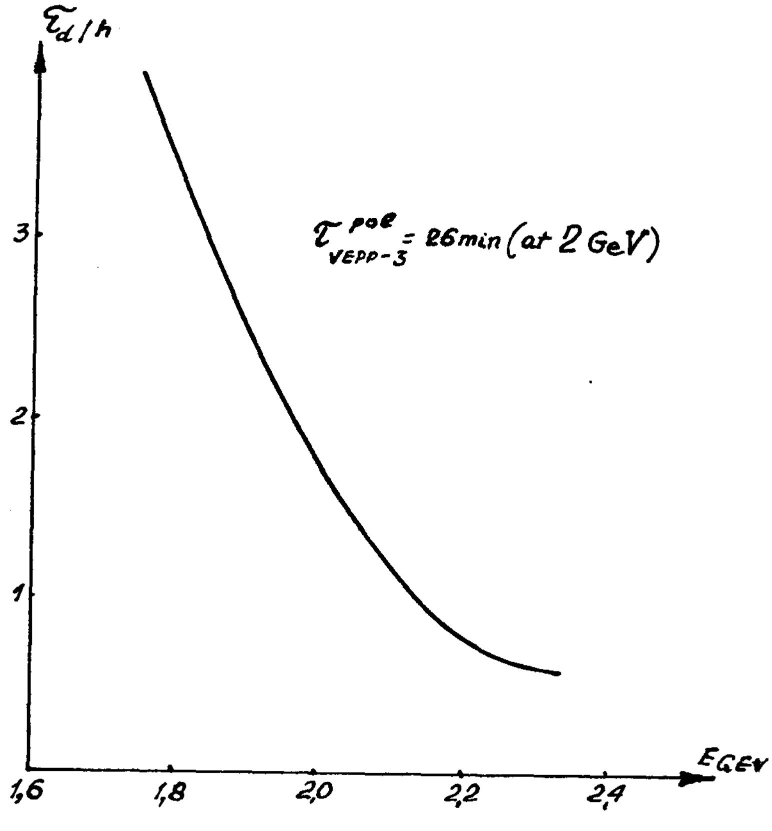


$\vec{n}_o$
$\vec{n}_o$
$\pi$
$e^+$
$e^-$
$\vec{n}_o$ - in orbit plane
$\vec{n}_o$
$\vec{n}_o$
$\vec{s}$
$\frac{\pi}{2}$
$\vec{n}_o$
$n_o$

D
F
$\pi$
D
F
D
F
B4
D
F
$e^+$
$e^-$
$\frac{\pi}{2}$


Fig. 6.



$\tau_d/h$
$\tau^{pol}_{VEPP-3}$ = 26min (at 2 GeV)
3
2
1
1,6
1,8
2,0
2,2
2,4
$E_{GEV}$


Fig. 7.

There are no questions new in principle with respect to those already considered while planning ep experiments with longitudinally polarized colliding beams.

9. In the experiments with longitudinally polarized colliding beams it is of great importance to provide the control of helicities for interacting particles. At high energies the initial particle helicities make a dramatic effect on the cross sections of fundamental processes.

So, the electromagnetic process cross sections (proceeding through the single photon channel) depend on the relative helicity of $e^{\pm}$: with equal helicities (the total spin is equal to zero) this channel is completely closed and the processes of $e^+e^- \to \mu^+\mu^-$ kind proceed only due to diagrams of higher orders which make the total cross section of the process sharply decreased. But namely this circumstance enables one to hope for studying the higher orders of QED and possibly definition of contributions from other interactions.

At weak interactions proceeding via $Z^o$, $W^{\pm}$ bosons the absolute helicities of colliding particles become also essential. So, the reaction $e^+e^- \to Z^o$ will only proceed with left helicity of $e^-$ and right helicity of $e^+$. In other variants this process should be profoundly suppressed and then some other interactions will become noticeable. The similar effects are also characteristic for other fundamental interactions $q^{\pm}q^{\pm}$, $e^{\pm}q^{\pm}$, which will dominate in the experiments with $p\bar{p}$, pp, $e^{\pm}p$ colliding beams.

There could be some various ways for the control of helicities of interacting particles. If there is no polarizing mechanism just in the experiment, the beam polarization is established by injection of initially polarized particles. For the experiments of not too high accuracy, as was mentioned above, it is enough to have only one beam polarized. The effects connected with helicities can naturally be found out with variation of polarization sign of initially injected particles and the comparison of interactions of the polarized and unpolarized beams. The fine and weak effects can be detected while varying the particle polarities due to spin overturn with slow adiabatic pass through the spin resonance with external RF electromagnetic field (with no perturbation of the orbital motion). This process has been realized at VEPP-2M without any substantial decrease in the polarization level.

The independent effect (on sign and level) on polarization of particles circulating in the same storage ring can be produced due to relevant time modulation of RF field and the use of fields propagating with the velocity of light towards the particles to be affected.

For $e^{\pm}$ storage ring under conditions when radiative polarization is dominant, the equilibrium polarization is always such that the sum of spins $e^+$ and $e^-$ equal to zero; correspondingly the particle helicities are equal at the interaction section with longitudinal polarization. For studying interactions as functions of helicities one has to use the "comparison mode" with forced depolarization of one of the beams. Greater possibilities for independent control of helicities provide the use of a two-track storage ring (of the "old" DORIS type). An example of the interaction section scheme providing the production of $e^+$ and $e^-$ with opposite helicities is given in Fig. 8.

With $e^{\pm}$ storage rings at high energies it is especially promising to use radiative polarization in HF laser fields propagating toward the polarizing beam.[26,27] In this case, at the point of interaction with the laser field one should have the longitudinal component of $\partial\vec{n}/\partial\varepsilon$ high enough and the laser field should be longitudinally polarized. This technique enables one to establish the helicities of colliding beams independently.

10. Depolarizing effect of the counter beam coherent fields in the case of longitudinal polarization at the beam collision point is mainly similar to that of transversal polarization.[17,18] Some specific feature is that the deflecting effect on the longitudinally polarized spin is produced by any component (transverse to the velocity) of the counter beam field. In the case of transversal spin orientation an influence is caused only by the orbital force component directed along the spin. This point, which is especially substantial for the usual case of the beams flat at the interaction point, should be taken into account while optimizing experimental conditions

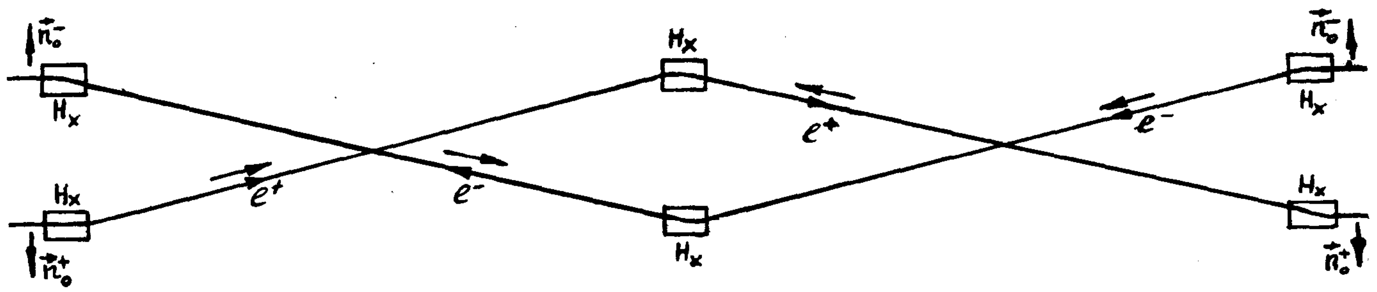



Fig. 8.

for getting high luminosity of longitudinally polarized colliding beams.

11. Above was considered the stable longitudinal polarization at a certain section of the storage ring from the view point of using this for implementation of colliding beams with pure helicities, only. Though, there are some other important applications of storage rings with similar structures. First of all, one should mention application of such storage rings in the mode of a thin and super-thin internal polarized target (when the orbital diffusion processes are suppressed with appropriate cooling) located at the section with longitudinal $\vec{n}_0$.

Such kind of experiments can turn out to be most promising, in particular, for studying the deep inelastic scattering on nucleons with given helicities of initial particles (these experiments are of special interest at high energies as at storage rings PETRA, PEP and then HERA, LEP). The attainable luminosity of such experiments is $10^{30} \to 10^{32}$ cm$^{-2}$ s$^{-1}$.

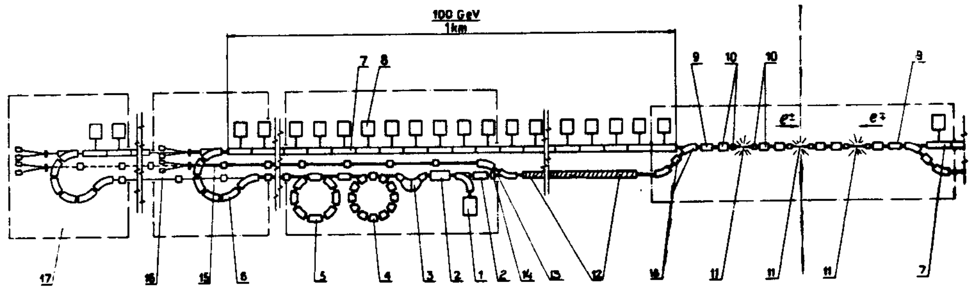
The use of the mode considered for proton storage rings enables one to carry out experiments with the given initial helicities under clean conditions with much higher luminosities (because of feasibility of higher proton currents including those polarized in comparison with currents at superhigh energies for $e^{\pm}$ case).

The mode considered *is of special interest* for operation with polarized antiprotons. As mentioned above, this mode is optimum for producing polarized $\bar{p}$ with the use of cooling (optimal polarization energy is 1-2 GeV).[20] The resulting rate for producing polarized $\bar{p}$ can be only one order lower than the total efficiency for $\bar{p}$ (now visible ultimate possibilities are of $10^8$ polarized $\bar{p}$ per second). Subsequent use of the considered mode at the desired experimental energy (generally speaking, at the other storage ring) can provide in future the luminosity up to $10^{33}$ cm$^{-2}$ s$^{-1}$.

The entire different application of cyclic storage rings with the structures, providing longitudinal $\vec{n}_0$ at the major part of the storage ring circumference, can be the producing of the high energy intense polarized muon beams.[28] If injecting into the track, for example, with two long straight sections where provided the longitudinal and with the same sign direction $\vec{n}_0$ in both straight sections the intense pion beam with an energy of tens or hundreds of GeV, the muons, generated by the pion decay in the long sections with momentum direction (in the system of pion) along the direction of its laboratory motion, will have nearly full energy of pions and well enough fixed laboratory helicity. The muons of the opposite helicity will be strongly deflected in energy and can easily be extracted from the beam.

12. New prospects for experiments with $e^+e^-$, $e\gamma$, $\gamma\gamma$ colliding beams with the given helicities will be opened up with development and creation of the electron-positron linear colliding beam facility with an energy of hundreds GeV - the VLEPP project[29] (experiments with electron polarized beam is envisaged in the SLC project[30]).

Generation of polarized electrons and positrons at energies above 100 GeV will be carried out with the use of synchrotron radiation of "worked-out" electrons and positrons in the long helical undulators (see Fig. 9) with further conversion of the longitudinally polarized $\gamma$-quanta with an energy of 10 MeV into the longitudinally polarized $e^+$ and $e^-$ and their further final acceleration and orbital radiative cooling down to the required very small emittances.




1. INITIAL INJECTOR
2. INTERMEDIATE ACCELERATOR
3. DEBUNCHER-MONOCHROMATIZER
4. STORAGE RING
5. COOLER-INJECTOR
6. BUNCHER
7. ACCELERATING SECTIONS
8. SHF SOURCE
9. PULSE DEFLECTOR
10. FOCUSING LENSES
11. COLLISION POINTS
12. HELICAL ONDULATOR
13. THE BEAM OF $\gamma$-QUANTA
14. CONVERSION TARGET
15. RESIDUAL ELECTRON BEAM
16. ELECTRON (POSITRON) BEAM EXPERIMENTS WITH STATIONARY TARGET
17. THE SECOND STEP
18. SPECTROMETER

The Scheme of VLEPP

Fig. 9.

By controlling the direction of $e^{\pm}$ spins prior the injection into the main linear accelerator one can provide the experiments with any required combination of helicities with ultimate luminosity of the VLEPP-facility (it is designed on the level of $10^{32}$ cm$^{-2}$ s$^{-1}$ for the whole operating range of energies $\sqrt{s}$ = 300 $\rightarrow$ 1000 GeV).

The highly effective conversion of electrons on laser targets with desired helicity[31,32] can allow to carry out the experiments with $e\gamma$ and $\gamma\gamma$ polarized colliding beams with luminosity nearing that of $e^+e^-$.

13. Carrying out the polarization experiments in high energy physics and especially the colliding beam experiments with particles with certain helicities becomes very important for development of elementary particle physics. The results of such experiments should entirely justify the considerable efforts necessary for their implementation.

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