# LONGITUDINAL POLARIZATION AND ACCELERATION OF POLARIZED BEAMS

I.A. Koop, BINP SB RAS, NSU and NSTU, Novosibirsk, Russia

*Abstract*

The paper describes a scheme of creation of the longitudinally polarized electron beam at the collision point of the future FCC-ee collider. A scheme is based on use of two 90-degrees spin rotators placed in appropriate points of the interaction region. The solenoid type spin rotators are proposed to use for that purpose. Advantages and disadvantages of the proposed approach are discussed.

## INTRODUCTION

There is a clear request for the longitudinal polarization at Z-peak [1]. Even collisions of un-polarized positrons with polarized electrons are of interest for the Weinberg angle measurement experiment, as it was done at SLC.

Still, a positron beam polarization would help very much in study and minimization of different systematics. In principle, a polarized of up to 50%-70% positron beam with only about 10 times lower intensity should be available – it can become polarized in about 5 min in 1-1.5 GeV wiggler damping ring and then be pre-accelerated in a linac to 20 GeV and finally ramped to a full energy by the booster synchrotron.

The full intensity polarized of up to 80%-90% electron beam will be produced like at SLC by a photoemission gun. After acceleration in a linac to 20 GeV it similarly to positrons will be accelerated in a booster synchrotron. Maintaining of the polarization in a synchrotron is discussed briefly in [2].

The effective control of the polarization in the collider and in a synchrotron will be provided by the longitudinal Compton backscattering polarimeter [3, 4]. In contrast to the transverse case the longitudinal one has an extremely large analyzing power, approaching to 75% at Z-peak and almost to 100% at W-threshold.

Below we will discuss two possibilities of organizing of the longitudinal orientation of the stable spin direction at the IP. In both cases the solenoid type spin rotators are proposed to be used.

## LONGITUDINAL POLARIZATION AT Z-PEAK

A combination of two $\pm 90^0$ spin rotators and an anti-symmetric horizontal chicane in between with 15 mr deflection angle at IP (relative to the solenoid axis) provides the needed longitudinal spin direction in the collision point, see the Figure 1. Such setup does not disturb the global spin motion due to mirror symmetry of all spin rotations. Therefore the stable spin axis remains a vertical all around a ring, as also the spin tune remains be as same $\nu=\nu_0=\gamma a$, as without any spin rotators. So, a spin precession frequency measurement can be used further for monitoring of the energy stability and for the energy calibration.

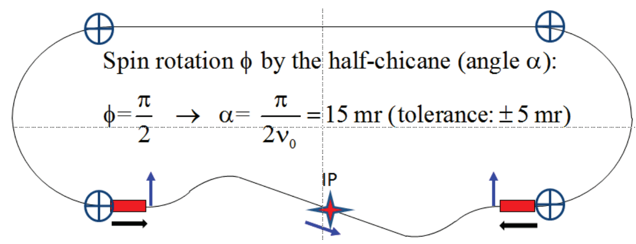


Figure 1: Top view on anti-symmetric layout of a set of $90^0$ spin rotations produced by solenoids and by bends in horizontal plane. The orbit deflection angle 15 mr provides $90^0$ spin rotation exactly at E=45.5 GeV.

The radiative depolarization rate is expected to be very small because of zero value of the spin-orbit coupling vector $\vec{d}$ everywhere in arcs, except the chicane bends. The spin relaxation rate is described by the famous DK formula [5]:

$$\tau_p^{-1} = \frac{5\sqrt{3}}{8} \lambda\!\!\!^{-}_e r_e c \gamma^5 \left\langle \frac{1 - \frac{2}{9}\left(\vec{n}\vec{\beta}\right)^2 + \frac{11}{18}\vec{d}^2}{|r^3|} \right\rangle$$

Here $\vec{n}(\theta)$ is a unity vector aligned along the equilibrium spin direction of a reference particle, $\vec{d}(\theta) \equiv \gamma \frac{\partial \vec{n}}{\partial \gamma}$ is the so-called a spin-orbit coupling vector, which describes the dependence of $\vec{n}$ from the energy, $r$ is the bending radius and other symbols have the obvious meaning.

In a flat normal ring $\vec{n}(\theta)$ is vertical independently of energy, hence $\vec{d}(\theta) = 0$. Some small contribution to $\vec{d}$ from dipoles of the chicane will decrease depolarization time from 190 hours to about 24 hours, if the field strength in these bends is same as in arcs.

ISBN 978-3-95450-172-4

## SOLENOID TYPE SPIN ROTATORS

Different optics schemes for compensation of by the solenoid induced coupling were suggested in 80-th by Litvinenko and Zholentz [5]. Most simple for realization is a scheme shown in the Figure 2. The total solenoid is divided in two halfs. Each half rotates spin around the longitudinal axis by the angle

$$\frac{\varphi}{2} = (1 + a)\frac{\int B\,dl}{Br}$$

The coupling is compensated by the normal quadrupole lenses inserted between the solenoids providing that the 2x2 transportation matrices satisfy to the condition [6]:

$$T_x = -T_y .$$

Main advantage of such a scheme is a flexibility in tuning the optics of a spin rotator. One can switch off the solenoids completely and retune the quads to provide the same beam transport as it was before.

The other requirement comes from the spin transparency condition. To cancel the contribution of the horizontal betatron oscillations to beam depolarization the transport matrix of such a partial spin rotator should be of the type shown in the Figure 2 [7]. In case of the $90^0$ total spin rotation angle both matrices $T_{x,y}$ became anti-diagonal.

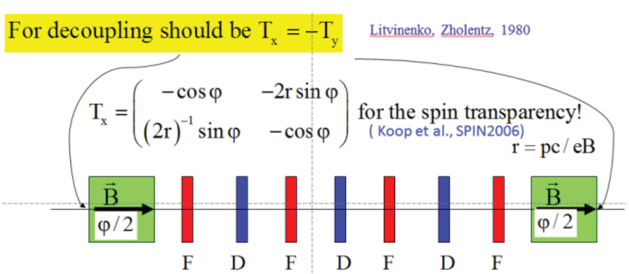


Figure 2: Spin transparent rotator optics scheme for the solenoid type partial Snake.

## LONGITUDINAL POLARIZATION AT HIGHER ENERGIES

At higher than 60 GeV beam energies the synchrotron satellites of integer and intrinsic resonances may overlap and make polarization life time very short. That is one of the plausible explanations of the LEP's observations [8].

The strength of the synchrotron satellites is proportional to a spin tune chromaticity. In a flat ring without snakes the spin tune chromaticity equals just to the tune $\nu_0$ :

$$\gamma\frac{\partial\nu}{\partial\gamma} = \nu_0 = 180 \qquad \text{for} \quad E = 80 \ \text{GeV}$$

We see that at 80 GeV the tune chromaticity becomes extremely large. But there is a trick which can help to solve a problem.

We can make same polarity of the longitudinal field in two $90^0$ spin rotators - one on the left and another on the right side from the IP. Then the whole device became a Siberian Snake. Now, let do the longitudinal polarization not in one but in 2 or 4 detectors, placed as shown in the Figure 3. In this example four interaction points divide $360^0$ ring azimuth on unequal segments and spin changes the direction from a vertical to anti-vertical after passing of each snake. Let $f$ < 0.5 is a fraction of the total circumference occupied by two short arcs, interleaved by two long arcs. Then the spin tune is equal to:

$$\nu = (1 - 2f)\nu_0$$

With $f$ chosen close to 0.5 it becomes arbitrarily small, but still not zero! Accordingly, the spin tune chromaticity becomes also much smaller than $\nu_0$, and this could make the polarization life time much longer.

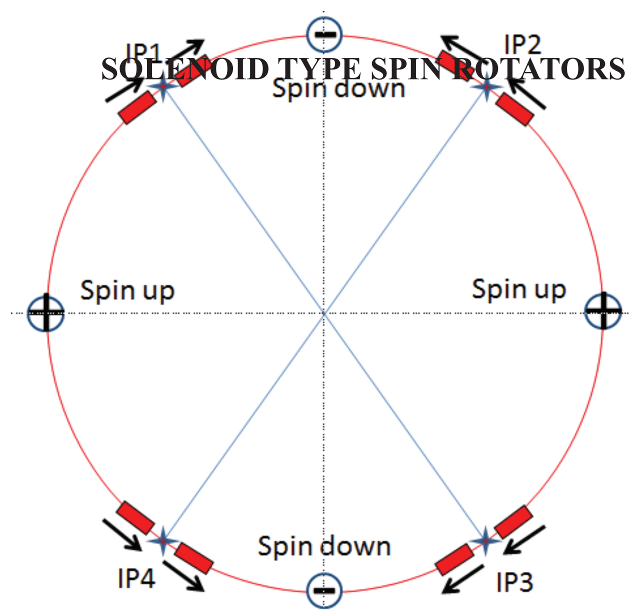


Figure 3: The longitudinal polarization scheme with 4 Siberian Snakes which divide a ring into 4 unequal sectors. The equilibrium spin direction is vertical in long sectors and is rotated by $180^0$ by each snake, which consists in turn of two $90^0$ spin rotators of solenoid type. Chicane magnets, which rotate spin in the horizontal plane and create the longitudinal spin component at IP (not perfectly in general), are not shown.

Such asymmetric division of the circumference on 2 or 4 sectors by the even number of snakes (in general) looks very profitable also for the acceleration of polarized beams to super-high energies [8, 9]. The only drawback is that spin tune is not constant during the energy ramp and may cover a wide dynamic range, say: $0.1 < \nu < 0.9$.

## CONCLUSION

Using $90^0$ spin rotators and ±15 mr magnet chicanes it is possible to organize a perfect longitudinal polarization



ISBN 978-3-95450-172-4

at IP of each interaction region at Z-peak. At higher energies one should care on minimization of the spin tune chromaticity. Siberian Snake approach provides a solution based on a choice of unequal arc angles between 4 interaction points. Still, the polarization vector becomes perfectly longitudinal only at a set of discrete energies: say at 45 and 135 GeV, depending on the chicane deflection angle.

Future spin tracking simulations should prove validity of the discussed above ideas.

## ACKNOWLEDGEMENTS

The author expresses his gratitude to Yu. Shatunov, S.R. Mane and A. Otboev for stimulating discussions and interest to this work.

## REFERENCES

[1] A. Blondel, “Physics motivation and requirements”, HF2014 Beijing, 9-12 October 2014.
[2] I. Koop, “Maintaining polarization in synchrotrons”, HF2014 Beijing, 9-12 October 2014.
[3] I. Koop, “Polarization issues and schemes for energy calibration”, HF2014 Beijing, 9-12 October 2014.
[4] M. Beckmann et al., “The Longitudinal Polarimeter at HERA”, Nucl.Instrum.Meth. A479 (2002) 334–348.
[5] Ya.S. Derbenev, A.M. Kondratenko , “Polarization kinetics of particles in storage rings”, Zh. Eksp. Teor. Fiz. 64 (June 1973) 1918-1929 (in Russian); Sov. Phys. JETP, vol.37, No.6 (Dec. 1973), pp. 968-973.
[6] A.A. Zholents, V.N. Litvinenko, “On the compensation of solenoid field effects by quadrupole lenses”, Preprint IYF 1981-080, Novosibirsk; see also DESY-L-TRANS-289
[7] I.A. Koop et al., “Spin transparent Siberian Snake and spin rotator with solenoids”, 17th International Spin Physics Symposium, Kyoto, Japan, 2-7 October, 2006; AIP Conference Proceedings Volume 915, American Institute of Physics, 2006, p.948-954.
[8] S.R. Mane, “Polarization at TLEP/FCC-ee: ideas and estimates”, preprint arXiv: 1406.0561v1 [physics.acc-ph] 3 June 2014.
[9] Yu. Shatunov, a talk at SPIN14 conference, October 2014, Beijing, China.

ISBN 978-3-95450-172-4