Longitudinal Polarization in Novosibirsk c-tau factory

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• C-tau complex with the longitudinally polarized electrons.

• Siberian Snakes Concept.

• Radiative self-polarization processes. Formulae Derbenev - Kondratenko.

• Few options with different number of snakes.

• Results and conclusion.
Novosibirsk c-tau complex layout

- Polarized e-source
- Positron Linac
- Positron Damping Ring
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Energy</td>
<td>1.0 – 3.0 GeV</td>
</tr>
<tr>
<td>Circumference</td>
<td>522 m</td>
</tr>
<tr>
<td>Crossing angle</td>
<td>60 mr</td>
</tr>
<tr>
<td>Emittances, $\varepsilon_x / \varepsilon_y$</td>
<td>4.8 / 0.025 nm</td>
</tr>
<tr>
<td>Number of bunches</td>
<td>270</td>
</tr>
<tr>
<td>Number of particles/bunch</td>
<td>$9 \cdot 10^{10}$</td>
</tr>
<tr>
<td>Total current</td>
<td>2.2 A</td>
</tr>
<tr>
<td>Beta function, $\beta_x / \beta_y$</td>
<td>50 / 0.5 mm</td>
</tr>
<tr>
<td>Sigma, $\sigma_x / \sigma_y$</td>
<td>15/0.1 (3 GeV) mkm</td>
</tr>
<tr>
<td>Luminosity</td>
<td>0.9 - 2.8 $\cdot 10^{35}$ cm$^{-2}$s$^{-1}$</td>
</tr>
</tbody>
</table>
Polarization scheme with 3 snakes (arc=120° +2 damping wigglers in the arc's middle)
Spin directions in the Novosibirsk Super c-tau factory
Transparent spin rotator (partial snake)

To decouple x,y-motions should be $T_x = -T_y$ (Litvinenko, Zholentz, 1980)

$$T_x = \begin{pmatrix} -\cos \varphi & -2r \sin \varphi \\ (2r)^{-1} \sin \varphi & -\cos \varphi \end{pmatrix}$$ - for the spin transparency! (Koop et al., SPIN2006)

$$r = \frac{pc}{eb}$$

Two solenoids rotate spin by the angle $\varphi$

All quads don’t need to be skewed!
180° spin rotators, in places 1, 2, 3
Equivalents of $180^0$ spin rotator, drifts 1, 2, 3

Floquet functions of snakes №1, №2 and №3, solenoids off

$\sqrt{\beta_x}, \sqrt{\beta_y}, \text{m}^{1/2}$

$s, \text{m}$
Depolarization time in presence of snakes

\[ \tau_p^{-1} = \frac{5\sqrt{3}}{8} \lambda_e r_e c \gamma^5 \left\langle \left| K^3 \right| \left( 1 - \frac{2}{9} (\mathbf{n} \mathbf{v})^2 + \frac{11}{18} \mathbf{d}^2 \right) \right\rangle \]

Here \( K = \rho^{-1}, \quad |\mathbf{v}| = 1 \)

Spin transparency cancels the betatron contribution to \( \mathbf{d} \):
\[ \mathbf{d} = \mathbf{d}_\gamma + \mathbf{A}_\beta, \text{ then:} \]
\[ \mathbf{d}^2 (0) = \frac{\pi^2}{4} \sin^2 \frac{\pi \mathbf{v}}{n_{\text{snk}}} \]
\[ \left\langle \mathbf{d}^2 \right\rangle = \mathbf{d}^2 (0) + \frac{\pi^2}{3} \frac{\mathbf{v}^2}{n_{\text{snk}}^2} \]

Placing damping wigglers in minimum of \(|\mathbf{d}|\) weakens depolarizing effects of SR

\[ \tilde{\mathbf{d}} = \gamma \frac{\partial \mathbf{n}}{\partial \gamma} \] is the spin – orbit coupling vector

\[ \mathbf{d}^2 (\theta) \quad \text{E} = 1 \text{ GeV} \]
\[ \mathbf{d}^2 (\theta) \quad n_{\text{snk}} = 1 \]

\[ \tilde{\theta} = \int K(\theta) d\theta \]
Self-polarization in presence of snakes

\[ \zeta_p = \frac{8}{5\sqrt{3}} \cdot \frac{(\pi / 2) \sin(\pi n_{\text{snk}} / n_{\text{snk}})}{\left\langle K_B^3 + |K_W|^3 \right\rangle 7/9 + \left[ \left\langle K_B^3 d^2(\theta) \right\rangle + |K_W|^3 d^2(0) \right]}^{11/18} \]

\[ K_W \equiv \rho_W^{-1} \]

Symmetric wigglers do not contribute to the nominator, but asymmetric will do. That can be used to polarize the positron beam.

\[ \bar{d}^2(\theta) = \frac{\pi^2}{4} \sin^2 \frac{\pi n_{\text{snk}}}{n_{\text{snk}}} \]

\[ \langle \bar{d}^2 \rangle = \bar{d}^2(0) + \frac{\pi^2}{3} \frac{\nu^2}{n_{\text{snk}}^2} \]

\[ \bar{d}^2(0) = \frac{\pi^2}{4} \sin^2 \frac{\pi n_{\text{snk}}}{n_{\text{snk}}} \]

\[ E = 1 \text{ GeV} \]

\[ n_{\text{snk}} = 3 \]

\[ \bar{\theta} = \int K(\theta) d\theta \]
Module of Spin-Orbital Function, 3 Snakes

3 snakes

$E, \text{GeV}$

- 3.0
- 2.9
- 2.8
- 2.7
- 2.6
- 2.5
- 2.4
- 2.3
- 2.2
- 2.1
- 2.0
- 1.9
- 1.8
- 1.7
- 1.6
- 1.5
- 1.4
- 1.3
- 1.2
- 1.1
- 1.0

$s, \text{m}$

$|\frac{dN}{dy}|$

Snakes
Radiative polarization relaxation time, $\tau_{\text{rad}}$

With snakes on the equilibrium radiative self-polarization degree $P_{\text{rad}}=0$.

So, after injection of a beam its polarization degree drops down exponentially with $\tau_{\text{rad}}$ time constant.

Therefore, the continuous injection of fresh beam portions is required!
Polarization degree overview

Mixture of depolarized and fresh polarized beams:

\[ \langle P \rangle = P(0) \frac{\tau_{rad}}{\tau_{rad} + \tau_{beam}} \]

\[ P(0) = 90\% \]

The effective beam refreshment time \( \tau_{beam} = 100 \text{ s} \) looks feasible with our polarized e\(^-\) source.
What about polarized positrons?

• The production rate of polarized electrons from a source is unlimited.

• But use of the Sokolov-Ternov mechanism to produce the polarized positrons in ~1 GeV Damping Ring is not so effective.

• Only 40-60% of the polarization degree (in average) can be achieved by this manner. Polarization time about 1 min looks feasible.

• Besides, the double set of the Siberian Snakes should be installed in two storage rings to handle the longitudinal polarization of both beams.

• The question arises: is there any sense to go this way? How much we gain from having 40-60 % for positrons and 70-80% of electrons polarization?

• Until now we do not consider this option seriously.
Conclusion

• **1 snake** provides up to 80% - 90% of the longitudinal polarization at low energies: \( E < 1.5 \text{ GeV} \). This option can be considered as a first stage for polarization program.

• **3 snakes** provide also high enough polarization degree, about 70-80%, in the energy range \( E < 2.5 \text{ GeV} \) and only about 50% at 3 GeV. Currently this is the main scenario, because it fulfils to the main physics program requirements.

• No preferable sign of the polarization! This helps to fight with not all but many systematic errors, caused by the detector registration efficiency asymmetries.

• The preliminary design of the superconducting solenoids and of the polarized electron source was already done. Practical experience was achieved in 90-th at AmPS stretcher ring in NIKHEF, Amsterdam.

• And the last remark: the tolerances on the quads gradient integrals and the solenoid field integrals in Snakes are not too much stringent: in a range of few percent.