# Spin-Alignment Dynamics in Curved Electron Beams: A Field Coupling Model

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**Abstract**

In this work, we propose a spin alignment model for electrons circulating on curved trajectories in strong magnetic fields, such as those encountered in synchrotron storage rings. The model predicts three metastable preferred spin orientations, leading to distinct modes of inter-electron field coupling, enhanced stability, and potentially reduced requirements for external magnetic confinement. Experimental verification is suggested through high-precision spin-polarization measurements. The described predictions are based on the Le-Doigt Roton-Quantum-Model proposed by the author.

## 1 Model Description

Electrons moving along curved trajectories experience continuous "magnetic" interaction, resulting in spin precession and alignment phenomena. Beyond the conventional Sokolov-Ternov polarization effect, we propose a triplet of metastable spin alignment minima:

1. **Primary minimum:** Spin axis aligned radially inward towards the center of rotation.
2. **Secondary minimum:** Spin axis aligned along the global rotational axis of the storage ring (vertical direction).
3. **Tertiary minimum:** Spin axis aligned parallel to the direction of motion (tangential to the orbit).

Transitions between these minima require external perturbations (e.g., photon emissions, scattering events) to overcome local field symmetries.

## 2 Physical Consequences

Each spin alignment leads to characteristic interaction effects:

- **Radial spin alignment** enables the formation of long-range entanglements between electrons on opposite sides of the ring. This behavior is analogous to the functioning of satellite dish communication, allowing field-based attraction beyond direct magnetic interaction.

- **Axial spin alignment** fosters local spin-coupled electron clustering, enhancing local field coherence and permitting electrons to maintain closer proximity within the same sector of the orbit. Or in other words, this orientation allows a state where there is no more long-term precession needed and the electron-spin can keep its rotation axis. This axis is also parallel to the rotation axis of the whole rotation ring. This also provides an additional force into the direction of the rotation-center.
- **Tangential spin alignment** stabilizes rotational "trains" of electrons, minimizing internal friction between neighbouring particles and allowing for more efficient motion along the orbit with reduced external magnetic guidance requirements. The electrons will experience an attraction to each other along the travelling direction.

## 2.1 Visualization

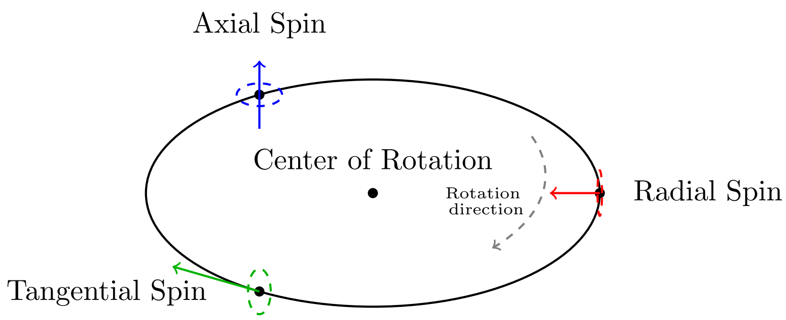


Figure 1: Schematic of spin orientations radial, axial and tangential

## 2.2 Spin-Coupling

If rotating electrons happen to find a coupling partner with the exact same radial orientation, they might happen to enter an "entangled state. This means, that they stabilize and keep each other in their exact current axis position - even over very long distances. This entanglement will be kept even if they are rotating and adapting their shared rotation axis together. As a side-remark from the Roton-model: entangled electrons typically attract each other as long as the "energy density field" does not keep them from coming closer.

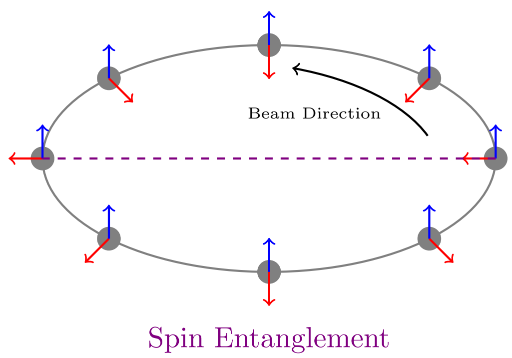


Figure 2: Spin-Coupling possibility

The diagram shows the entanglement variant with opposite spin as with "entangled" electrons in an atomic orbit. This requires though, that electrons with both types of spin directions (inwards, outwards) are present in the loop.

*Prediction:* We expect the amount of electrons with outward and inward spin to be similar.

# 3 Experimental Implications

The model suggests that careful measurements of spin polarization dynamics, using Compton polarimetry or Mott scattering techniques at multiple locations around the storage ring, could detect the presence of multiple metastable spin configurations. Deviations from standard polarization build-up rates or asymmetries in field alignment would support the model's predictions.

Furthermore, observing enhanced beam stability at reduced magnetic confinement could indicate spin-induced self-stabilization phenomena.

wieviele elektronen?

## 3.1 Disturbances

These predictions hold for more or less undisturbed rotation, for instance for radially "coupled" Electron-Pairs in an atomic shell. Or for axially rotating valence-electrons. In context of an electron acceleration ring the following environmental interactions might make the measurements of these effects dificullt: Matter in the rotation plan of the accelerator, Magnetic material, induced magnetic field.

## 3.2 Synchrotron Setups

Synchrotron experiments typically use electrons to be emitted as clusters or bunches. First important thing is, that we actually have enough electrons such that an entanglement might be possible.

| **Synchrotron** | **Electrons in Ring** | **Electrons per Bunch** | **Remarks** |
|---|---|---|---|
| LEP (CERN, historical) | $\sim 10^{12}$ | $\sim 10^{11}$ | 4 bunches per beam, 27 km circumference |
| BESSY II (Berlin) | $\sim 10^{10}$ | $\sim 10^{9}$ | $\sim$ 400 bunches, compact storage ring |
| ESRF (Grenoble) | $\sim 5 \times 10^{12}$ | $\sim 10^{10}$ | 992 bunches, ultra-short pulses |
| SLS (PSI, Switzerland) | $\sim 10^{11}$ | $\sim 10^{9}$ | $\sim$ 500 bunches, low emittance |
| ALS (Berkeley) | $\sim 10^{10}$ | $\sim 10^{9}$ | 328 bunches, optimized for soft X-rays |
| PETRA III (DESY) | $\sim 10^{11}$ | $\sim 10^{9}$ | 40 bunches in top-up operation |

Table 1: Typical electron numbers and bunch sizes in selected synchrotron facilities.

These Methods might favour some of the rotation types:

- **Radial:** Bunches might aligned themselves opposite each other.
- **Axial and Tangential:** Electrons might favour local smaller spin clusters
- **Tangential:** Stable axis alignment with some attraction to center even without entanglement.

### 3.3 Experimental evidence on electron spin

| **Experiment** | **Observed Effect** | **Relevance to Model** |
|---|---|---|
| Sokolov-Ternov Effect | Spontaneous spin polarization along vertical axis | Supports axial spin preference due to curved motion |
| LEP Polarization (CERN) | Stable vertical spin alignment observed | Confirms existence of preferred spin directions (axial mode) |
| Compton Polarimetry (SLAC, HERA) | Measurement of spin orientation via Compton scattering | Demonstrates that spin orientations are not random; field-dependent alignment possible |
| BESSY II Spin Manipulation | Controlled flipping of spin orientation via magnetic fields | Indicates metastable spin states, supports multiple spin minima concept |
| RHIC Spin Program (BNL) | Investigation of longitudinal and transverse proton spin dynamics | Confirms measurable complex spin behavior under curved trajectories |

Table 2: Key experiments providing evidence for spin alignment and metastable spin states in particle accelerators.

Terms:
"Longitudinal" spin: Spin parallel to particle flight direction = Axial "Transverse" spin: Spin perpendicular to particle flight (up/down, or left/right) "Spin along vertical axis": Special case of transverse spin, specifically along Earth's vertical (up/down) direction.

# 4 Conclusion

Assessment: In synchrotron practice, the vertical (axial) alignment of the spin seems to be favoured. Taking the direction of rotation around the synchrotron. Avoiding the need of the spin to change against axial directions.

| Factor | Explanation |
|---|---|
| Sokolov-Ternov effect | Quantum electrodynamics effect: Synchrotron radiation flips spins statistically toward vertical alignment. |
| Magnetic fields | Strong vertical (normal to orbit plane) magnetic fields dominate the spin dynamics. |
| Geometry | In a circular orbit, vertical spin (axial) is the most "stable" under the magnetic curvature and radiation damping. |
| Radial forces | Centripetal forces dominate particle motion, but they do not stabilize spin radially without special magnetic tricks. |

Table 3: Observed effects

What might scatter the prediction 1 regarding entangled radial spin orientation: - Distance too high for spontaneous entanglement. - Strong magnetic fields of the synchrotron influence the spin-direction. - Parallel orientation of the electrons in vertical direction is a more local effect and keeps axis from tilting.
This field coupling model offers a geometric and dynamical extension to conventional spin-polarization theories in synchrotrons, proposing experimentally testable

predictions. The implications for high-efficiency beam storage and quantum coherent field manipulations warrant further theoretical and experimental investigation.

## References


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