Note on “frame transformation induced” spin flip when comparing polarized Fixed Target vs. relativistic polarized beam interaction.

S. Heppelmann

For relativistic particles, interactions are simpler if we calculate spin in the helicity frame, were gauge interactions do not flip the spin. But for the high energy interaction of a polarized particle at rest, there is no unique connection to the helicity frame for the initial state. When a high energy virtual photon is absorbed by an electron or quark at rest, the component of spin out of the scattering plane is unchanged but the other two components of spin do flip. When the same process is studied in the collider environment, with helicity and transverse spin states, no such flip seem to be present. This is understood when the transformation between frames is analyzed carefully but it can lead to confusion, when defining the <u>most natural coordinate systems (angles)</u> when comparing the same processes in fixed target and collider experiments.

For a Dirac spin ½ particle, moving in a EM field, the spin rotation matches the deflection of the trajectory so that helicity is preserved. If we measure the spin vector in a frame that follows the trajectory of the particle through the EM field, the spin does not change. For non-perturbative processes this is true up to terms proportional to (g-2). For perturbative processes, it is true in low order for the relativistic limit.

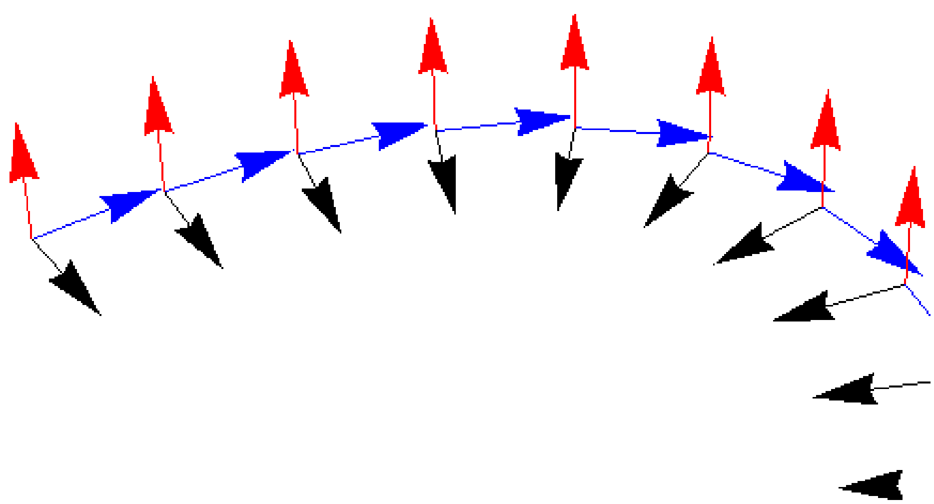

Figure 1: In this figure we show the natural frame to measure the spin of a particle as it moves through a gauge field. At each point, the motion is in the blue direction and with deflection due to the field around the red direction. The spin, as measured with the red-blue-black coordinate system is quite stable in the relativistic limit.

For a relativistic particle that collides with an exchanged photon or gluon (gauge interaction) and scatters backward the picture looks like Figure 2. Again, if the coordinate system is chosen correctly, wrapping around as the particle scatters, the spin is preserved relative to the changing coordinate system.

To be specific. Assume the initial blue direction is the z direction. The red is the y direction and the black is the x direction.

The two initial transverse directions define the x and y axis directions.

After the scattering, the final state coordinate system that we use to correspond to “null spin change” will be the (-x) ,y and (-z) direction where the scattering plane is normal to the y axis.

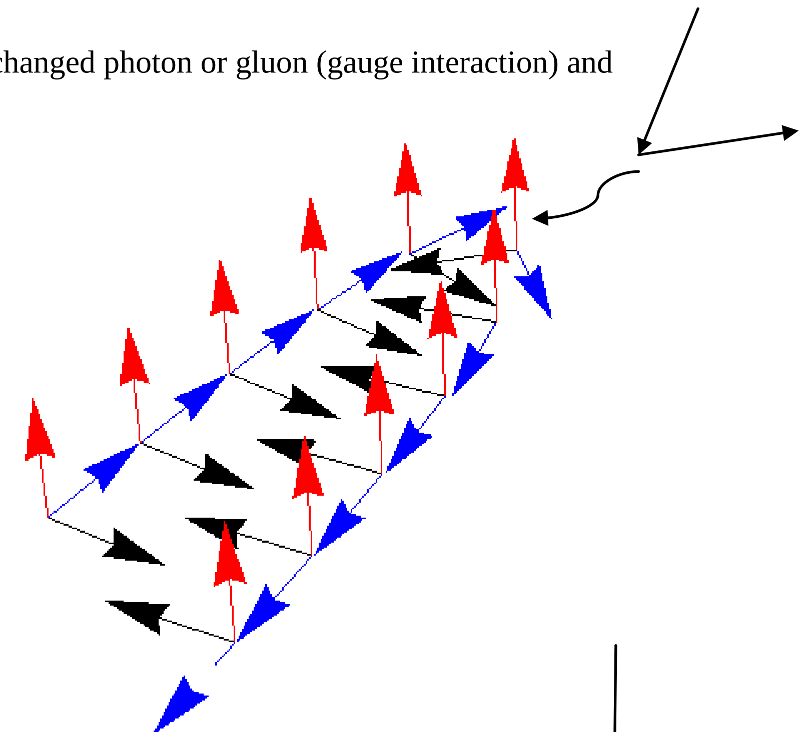

Figure 2: A Dirac Fermion with mot direction that scatters backward fro exchanged when some other particle Fermion.

Now suppose we have a Fermion that is at rest. Again in Figure 3 the z axis is in blue and y is red. We can apply these frame ideas only for relativistic moving Fermions so we boost to a frame where the Fermion is moving in the z direction toward the virtual photon. Then we have two body scattering with relativistic particles in both the initial and final state. The scattering plane is still perpendicular to y direction. The three directions {x,y,z} are the same as before the boost. The natural coordinate system before the scatter is {x,y,z} in the boosted frame. The Fermion scatters as in Figure 2. The natural frame after transferring momentum in the z direction will be {-x,y,-z} and the recoiling Fermion will be moving with momentum in the –z direction. The z component of spin flips in the scattering process but the final state helicity is measured reltive to the –z direction and is still unchanged. However, the x component of spin seems to flip as well.

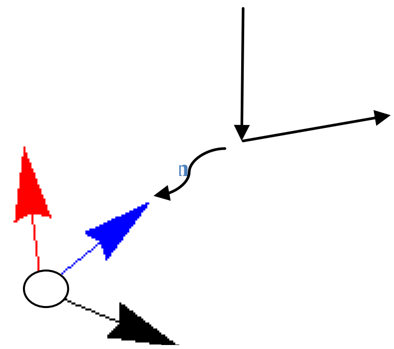

Figure 3: A projectile scatters from this spin ½ Dirac Fermion that is initially at rest. Assume that the transferred momentum is along the z axis and the Fermion recoils in the (-z) direction.

Finally, we undo the boost from before and return to the original frame, again boosting along the z axis. These direction unit vectors {-x,y,-z} are unchanged again by the inverse boost. The final state Fermion will be relativistic in both frames so initial and final state helicity can be connected to the initial coordinate system {x,y,z} that was used to describe the spin of the initial state proton at rest.

Conclusion:

If we scatter a photon from a relativistic Dirac Fermion, helicity is preserved. The direction of motion will change but the component of spin along that direction will be preserved. If the scattering plane of the event is normal to the y axis, then the component of spin along the y axis is is preserved in the scattering process. In the special frame, the z and x directions will have rotated around y but the spin along any of the 3 special frame directions will be unchanged. For backward scattering in Figure 2, the y component of spin is unchanged by the scatter but there is a coordinate system related sign change for the x component of spin.

In the case of Figure 3, we scattering from a proton initially at rest. In this case, there is no initial state helicity frame because there is no direction of motion. If momentum is transfer along the z direction and with the scattering plane normal to the y direction, then the y component of the resting particle's spin is preserved in the scattering process. However, the x component of spin before scattering becomes the –x component after scattering. This leads to an apparent spin flip for the x component of the struck Fermion along the x direction only.

It is well known in polarized electron scattering experiments that the longitudinal spin of an electron at rest flips when it is struck with a virtual photon (in the longitudinal direction).

So for a quark in a proton that is struck by something at RHIC and ends up in the FMS, the x and y components of the transverse spin of the initial quark are preserved by a perturbative (leading order) exchange (forward small angle limit).

However, for the same scattering process, if it is a quark at rest (in a polarized proton at rest) that gets struck. The out of plane transverse component of spin is preserved but the in plane transverse component of spin has an apparent spin flip due to a frame change.