Bullet Statements

Sivers Function

The Sivers function describes the correlation between the momentum direction of the struck quark and the spin of its parent nucleon.

A non-vanishing Sivers function for the sea quarks is evidence there is sea quark orbital angular momentum (OAM).

If sea-quark Sivers asymmetry is non-zero, then sea quarks have non-zero OAM.

A non-zero Sivers asymmetry from SpinQuest is "smoking gun" evidence for sea quark OAM

SpinQuest will measure the correlation between the angular distribution of the di-muons and the proton spin. If this is non-zero, then the antiquarks must have some orbital angular momentum.

The first measurement of the sea quark Sivers function is not SpinQuest but has been performed by the Star collaboration at RHIC using W/Z boson production rather than Drell-Yan. https://arxiv.org/pdf/1511.06003.pdf

This may be replaced by:

Initial attempts to measure the Sivers asymmetry for sea quark Sivers have been reported by the STAR collaboration at RHIC using W/Z boson production. Their data is statistically limited and favor a sign-change only if TMD evolutions effects are significantly smaller than expected. Star publication: https://arxiv.org/pdf/1511.06003.pdf and study of the sign change of the Sivers function https://arxiv.org/pdf/1612.06413.pdf

SpinQuest will perform the first measurement of the Sivers asymmetry in Drell-Yan pp scattering from the sea quarks.

The gauge-invariant definition of the Sivers function predicts the opposite sign for the Sivers function in SIDIS compared to processes with color charges in the initial state and a colorless final state such as Drell-Yan and W/Z boson production. In W/Z production, it is guaranteed that an anti-quark is involved as in the Drell-Yan process.

SpinQuest will explore the properties of the nucleon's spin composition by investigating the correlation of the light antiquarks motion relative to the nucleon spin.

SpinQuest will explore the interference between spin-flip and non-flip amplitudes with phase dependence.

SpinQuest can test the interplay between time-reversal symmetry and gauge symmetry: This can be understood by applying time-reversal to the quark fields in the operator definitions of the Parton densities and how the gauge link provides the phase for the interference. The Sivers asymmetry manifests like other naive T-odd observables because one is not integrating with such a measurement over transverse momentum.

The transverse SSA is odd under naive time reversal (time-reversal of three momenta and angular momenta) requiring interference of amplitudes with different helicities and phases.

The Sivers function and other TMDs are recognized as a tool to study spin-orbit correlations, providing experimental observables for studying orbital angular momentum.

SpinQuest is attempting to push the proton beam intensity frontier on a solid polarized target (specifically instantaneous intensity).

SpinQuest uses the longest target cell (and most volume) ever ran in a 1 K evaporation polarized target system.

Boer-Mulders function

The Boer-Mulders function describes a correlation between the transverse spin (polarization) and the transverse momentum of a quark inside an unpolarized hadron. The Boer-Mulders function (commonly denoted by h_1) describes the net polarization of quarks inside an unpolarized proton. Protons and quarks are both spin-1/2 particles that can be polarized in specific directions (they can have spin up or spin down in a specific direction). If one averages over the polarization states of the proton, then we call it an unpolarized proton (the net polarization averaged over many protons in a proton beam for instance is then zero). It turns out that the quarks can be polarized on average even inside such an unpolarized proton, as long as they are not moving exactly along the proton direction. If the proton moves along the z direction say, then the quarks can have some transverse momentum k_T with respect to the proton momentum, which together define a plane. The quarks can then have a net polarization orthogonal (or transverse) to that plane. A nonzero Boer-Mulders function means that there is such a net quark polarization.

Other Numbers and Important Points

The max intensity is $4X10^{12}$ protons/spill with a 4.4 seconds spill

The max annual proton count is $7X10^{17}$ protons/year

Use ~96% max proton polarization (average will be about 75%)

Use ~45% max deuteron polarization (average will be about 30%)

The cooling power of the He-evaporation refrigerator is 1.4 W at 1 K assuming a flow rate of 20 SLPM (normal operation). The pumps and fridge are capable of running at more than twice this flow rate while keeping the target around 1.1 K so the max cooling power while running is around 3 W.

This is the highest cooling power DNP (Dynamic Nuclear Polarization) target in the world due to the high pumping rate and the refrigerator. This is important since we are attempting to run the highest proton intensity on a solid polarized target ever done.

This is also the highest proton intensity ever attempted on this type of superconducting target magnet.

[Collins, Hermes Sivers, After Star Update,

The Sivers function is one of the best known polarized TMDs and has a clear experimental signature. The Siver function is of particular interest because one expects it to be related to fundamental intrinsic features of the nucleon and to basic QCD properties. In fact, the Sivers distribution relates the motion of the quarks (gluons) to the nucleon spin S; then in order to build a scalar, parity invariant quantity S must couple to the only other available pseudo-vector, that is the Parton orbital angular momentum Lq (Lg).

Another feature of the Sivers distribution is that its origin at a partonic level can be traced in QCD interactions between the quarks (gluons) active in inelastic high energy interactions and the nucleon remnants and so is process dependent and have an opposite sign in Semi inclusive deep inelastic scattering and Drell-Yan.

Transverse SSA had been assumed to be negligible in hard scattering processes. They are odd under naive time reversal (time-reversal of three momenta and angular momenta) and thus require the interference of amplitudes with different helicities and phases. In QED and perturbative QCD these ingredients are suppressed. Therefore, in semi-inclusive DIS they must ascribe to the non-perturbative parts in the cross-section.

It was argued that left-right asymmetries in the distribution of unpolarized quarks in transversely polarized nucleons, an asymmetry that exists before the pion is formed in the fragmentation process, and that does not vanish at high energies. A decade after an initial proof by Collins that this SSA must vanish because of time-reversal invariance of QCD it was realized that this proof applies only to transverse-momentum-integrated distribution function. A gauge link, previously neglected in the definition of gauge-invariant distribution functions, invalidates the original proof for the case of transverse-momentum distribution functions. The gauge link provides the phase for the interference (required for naive-T-oddness), and can be interpreted as an interaction of the struck quark with the color field of the target remnant.

This inclusion of the gauge link has profound consequences on factorization proofs and on the concept of universality, which are of fundamental relevance for high-energy hadronic physics. A direct QCD prediction is a Sivers effect in the Drell-Yan process that has the opposite sign compared to the one in semi-inclusive DIS.