Essay

On the Strange Spin Asymmetry at RHIC

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Abstract

A peculiar effect in p-p and p-N (N for nucleus) was observed at Relativistic Heavy Ion Collider (RHIC). In p-p scattering with polarized incoming proton, there is asymmetry in the sense that the protons with vertical polarization with respect to scattering plane give rise to more neutrons slightly deflected to right than to left (see the figure of the article). In p-N scattering of vertically polarized protons, the effect is also observed for neutrons but is stronger and has opposite sign for heavier nuclei! The effect came as a total surprise and is not understood. It seems, however, that the effects for proton and nuclear targets must have different origin since otherwise it is difficult to understand the change of the sign.

Keywords: Spin asymmetry, RHIC, nucleus, proton, neutron.

The popular article "*Surprising result shocks scientists studying spin*" (see at`http://tinyurl.com/y9zk8xa6`) tells about a peculiar effect in p-p and p-N (N for nucleus) observed at Relativistic Heavy Ion Collider (RHIC). In p-p scattering with polarized incoming proton there is asymmetry in the sense that the protons with vertical polarization with respect to scattering plane give rise to more neutrons slightly deflected to right than to left (see the figure of the article). In p-N scattering of vertically polarized protons the effect is also observed for neutrons but is stronger and has opposite sign for heavier nuclei! The effect came as a total surprise and is not understood. It seems however that the effects for proton and nuclear targets must have different origin since otherwise it is difficult to understand the change of the sign.

The abstract of the original article [1] (see `http://tinyurl.com/y72px42v`) summarizes what has been observed.

During 2015 the Relativistic Heavy Ion Collider (RHIC) provided collisions of transversely polarized protons with Au and Al nuclei for the first time, enabling the exploration of transverse-single-spin asymmetries with heavy nuclei. Large single-spin asymmetries in very forward neutron production have been previously observed in transversely polarized p+p collisions at RHIC, and the existing theoretical framework that was successful in describing the single-spin asymmetry in p+p collisions predicts only a moderate atomic-mass-number (A) dependence. In contrast, the asymmetries observed at RHIC in p+A collisions showed a surprisingly strong A dependence in inclusive forward neutron production. The observed asymmetry in p+Al collisions is much smaller, while the asymmetry in p+Au collisions is a factor of three larger in absolute value and of opposite sign. The interplay of different neutron production mechanisms is discussed as a possible explanation of the observed A dependence.

Since a diffractive effect in forward direction is in question, one can ask whether strong interactions have anything to do with the effect. This effect can take place at the level of nucleons and a quark level and these two effects should have different signs. Could electromagnetic spin orbit coupling (see `http://tinyurl.com/y7akvgns`) cause the effect both at the level of nucleons in p-N collisions and at the level of quarks in p-p collisions? If so, the explanation would not involved new physics. Note however that the proposed generation of dark variants of M_{89} mesons is associated with peripheral collisions to which one can assign quantum criticality [2]. Therefore one must keep mind open.

1. Spin-orbit interaction effect is relativistic effect: the magnetic field of target nucleus in the reference frame of projectile proton is nonvanishing: $\mathbf{B} = -\gamma \mathbf{v} \times \mathbf{E}$, $\gamma = 1/\sqrt{1-v^2}$. The spin-orbit interaction Hamiltonian is

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$$H_{L-S} = -\mu \cdot \mathbf{B} \ ,$$

where

$$\mu = g_p \mu_N \mathbf{S} \ , \quad \mu_N = \frac{e}{2m_p}$$

is the magnetic moment of polarized proton proportional to spin S, which no has definite direction due to the polarization of incoming proton beam. The gyromagnetic factor g_p equals to $g_p = 2.79284734462(82)$ holds true for proton.

2. Only the component of $\mathbf{E}$ orthogonal to $\mathbf{v}$ is involved and the coordinates in this direction are unaffected by the Lorentz transformations. One can express the transversal component of electric field as gradient

$$E_r = -\partial_r V \frac{\mathbf{r}}{r} \ .$$

Velocity $\mathbf{v}$ can be expressed as $\mathbf{v} = \mathbf{p}/m_p$ so the spin-orbit interaction Hamiltonian reads as

$$H_{L-S} = \gamma \frac{g_p e}{2m_p} \frac{1}{m_p} \mathbf{L} \cdot \mathbf{S} \frac{1}{r} \partial_r V \ .$$

For polarised proton the effect of this interaction could cause the left-right asymmetry. The reason is that the sign of the interaction Hamiltonia is opposite at left and right sides of the target since the sign of $L = r \times p$ is opposite at left- and right-hand sides. One can argue as in non-relativistic case that this potential generates a force which is radial and proportional to $\partial_r[(\partial_r V(r))/r)]$.

Consider first the scattering on nucleus.

1. Inside the target nucleus one can assume that the potential is of the form $V = kr^2/2$: the force vanishes! Hence the effect must indeed come from peripheral collisions. At the periphery responsible for almost forward scattering one as $V(r) = Ze/r$ and one has $\partial_r(\partial_r V(r))/r) = 3Ze/r^4$, $r = R$, R the nuclear radius. One has $R = kA^{1/3}$ for a constant density nucleus so that one has $\partial_r(\partial_r V(r))/r) = 3k^{-4}eZA^{-4/3}$.

   The force decreases with A roughly like $A^{-1/3}$ but the scattering proton can give its momentum to a larger number of nucleons inside the target nucleus. If all neutrons get their share of the transversal momentum, the effect is proportional to neutron number $N = A - Z$ one would obtain the dependence $Z(A-Z)A^{-4/3} \sim A^{2/3}$. If no other effects are involved one would have for the ratio r of Al and Au asymmetries

$$r = \frac{Al}{Au} \sim \frac{Z(Al)N(Al)}{Z(Au)A(u)} \times [\frac{A(Au)}{A(Al)}]^{4/3} \ .$$

   Using $(Z, A) = (13, 27)$ for Al and $(Z, A) = (79, 197)$ for Au one obtains the prediction $r = .28$. The actual value is $r \simeq .3$ by estimating from Fig. 4 of [1] (see `http://tinyurl.com/y72px42v`) is not far from this.

2. This effect takes place only for protons but it deviates proton at either side to the interior of nucleus. One expects that the proton gives its transversal momentum components to other nucleons - also neutrons. This implies that sign of the effect is same as it would be for the spin-orbit coupling when the projectile is neutron. This could be the basic reason for the strange sign of the effect.

Consider next what could happen in p-p scattering.

1. One must explain why neutrons with R-L asymmetry with respect to the scattering axis are created. This requires quark level consideration.

2. The first guess is that one must consider spin orbit interaction for the quarks of the polarized proton scattering from the quarks of the unpolarized proton. What comes in mind is that one could in a reasonable approximation treat the unpolarized proton as single coherent entity. In this picture u and d quarks of polarized proton would have asymmetric diffractive scattering tending to go to the opposite sides of the scattering axis.

3. The effect for d quarks would be opposite to that for u quarks. Since one has $n = udd$ and and $p = uud$, the side which has more d quarks gives rise to neutron excess in the recombination of quarks to hadrons. This effect would have opposite sign than the effect in the case of nuclear target. This quark level effect would be present also for nuclear targets but nucleon level effect would be possible only for nuclei with $A - Z > 0$.

As found, the model does not involve directly many-sheeted space-time except possibly via the assumption that polarized proton scatters from the entire target proton in electromagnetic sense.

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