

Double-spin transverse asymmetries in Drell-Yan processes

V. Barone

*Dipartimento di Fisica Teorica, Università di Torino and INFN, Sezione di Torino, 10125 Torino, Italy
and II Facoltà di Scienze MFN, 15100 Alessandria, Italy*

T. Calarco and A. Drago

*Dipartimento di Fisica, Università di Ferrara and INFN, Sezione di Ferrara, 44100 Ferrara, Italy
(Received 3 February 1997)*

We calculate the double-spin transverse asymmetries for the Drell-Yan lepton pair production in pp and $\bar{p}p$ collisions. We assume the transverse and the longitudinal polarization densities to be equal at a very small scale, as is suggested by confinement model results. Using a global fit for the longitudinal distributions, we find transverse asymmetries of order of 10^{-2} at most, in the accessible kinematic regions. [S0556-2821(97)03511-X]

PACS number(s): 13.88.+e, 12.38.Bx, 14.20.Dh

The transverse polarization distribution of quarks (or antiquarks) $h_1^{q,\bar{q}}(x,Q^2)$, originally introduced by Ralston and Soper [1] and studied in more detail in recent years [2–4], is totally unknown from an experimental viewpoint. The reason is that h_1 is a chirally odd quantity [2] and hence cannot be measured in deep-inelastic scattering. The best way to determine h_1 is by pp or, at least in principle, $\bar{p}p$ collisions with two transversely polarized beams.¹ The measurement of h_1 in proton-proton collisions is now a chapter of the physics program of the STAR and PHENIX experiments at the BNL Relativistic Heavy Ion Collider (RHIC) [6] and of the proposed HERA- \vec{N} experiment at the DESY ep collider HERA [7]. A careful analysis of the theoretical situation is, therefore, called for.

What is planned to be measured is the double-spin transverse asymmetry, whose operational definition is

$$A_{TT} = \frac{d\sigma_{\uparrow\uparrow} - d\sigma_{\uparrow\downarrow}}{d\sigma_{\uparrow\uparrow} + d\sigma_{\uparrow\downarrow}}, \quad (1)$$

where the arrows denote the transverse directions along which the two colliding hadrons are polarized.

Among the processes initiated by pp scattering one can make a selection choosing those which are expected to yield the largest A_{TT} . In fact, since there is no analogue of h_1 for gluons [2], all processes taking place at the partonic level via qg or gg scattering give a large contribution to the denominator of Eq. (1) and a vanishing one to the numerator, thus producing a negligibly small A_{TT} [8,9]. This leaves us with only one promising reaction: the Drell-Yan lepton pair production. The double-spin transverse asymmetry for this process was calculated in [8,10,11] and found to be relatively large (~ 0.1 – 0.3 at $\sqrt{s} = 100$ GeV and for a dilepton mass

$M = 10$ GeV). The basic assumption made in Refs. [8,10] in order to calculate A_{TT} was that h_1^q and $h_1^{\bar{q}}$ are equal to the helicity distributions Δq and $\Delta \bar{q}$, respectively, at the experimentally probed momentum scales. Now, since it is known from confinement model calculations [12] that $h_1^q \approx \Delta q$ and $h_1^{\bar{q}} \approx \Delta \bar{q}$ only at very small Q^2 ($Q^2 \lesssim 0.5$ GeV²), the assumption above amounts to neglecting the difference between the QCD evolution of $h_1^{q,\bar{q}}$ and that of $\Delta q, \Delta \bar{q}$.² Now, the evolution of h_1 is driven at leading order by gluon emission and the first anomalous dimension for this process, although nonvanishing, is rather small [3], hence not much different from the corresponding anomalous dimension of the helicity distributions, which vanishes exactly. However, if one goes from the space of moments to the x space, the difference between the evolutions of h_1 and Δq becomes large [12,13] at small x and affects all the observables which are sensitive to this kinematic region. This was first pointed out in [12], where a confinement model calculation of h_1 and A_{TT} was presented. It was found there that A_{TT} is rather small, of order of few percent. In what follows we shall confirm and extend the findings of [12] about A_{TT} in a more model-independent way.

Considering only the quark-antiquark annihilation graph³ the double-spin transverse asymmetry for the pp (or $\bar{p}p$) Drell-Yan process mediated by a virtual photon is given by

²A different procedure to relate the transverse distribution to the longitudinal and unpolarized distributions is adopted in [11] but again the peculiarity of the QCD evolution of h_1 is overlooked and results quantitatively similar to those of [8,10] are obtained.

³The contribution of next-to-leading order (NLO) diagrams has been crudely estimated in [15] and found to correct the dominant term in the asymmetries by less than 10%. However, a complete computation of the NLO diagrams and of the NLO splitting functions for h_1 is not available yet, hence the result of [15] can be taken only as an evaluation of the theoretical uncertainty of the leading-order result.

¹Also semi-inclusive reactions would allow extracting h_1 but these processes are theoretically more complicated as they involve combinations of twist-three distributions and unknown fragmentation functions [5].

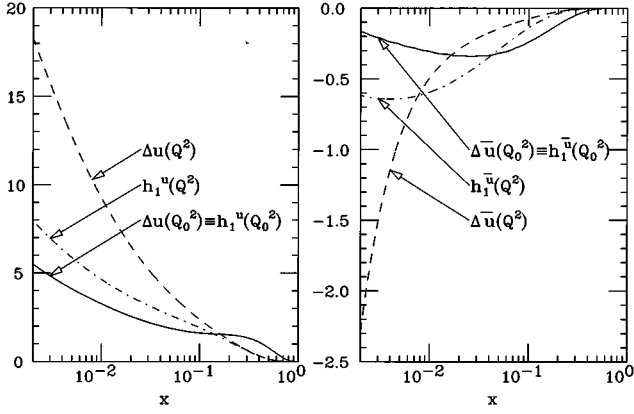


FIG. 1. The longitudinal and transverse polarization distributions for u and \bar{u} at the input scale $Q_0^2 = 0.23 \text{ GeV}^2$ and evolved up to $Q^2 = 25 \text{ GeV}^2$.

$$A_{TT} = a_{TT} \frac{\sum_q e_q^2 h_1^q(x_a, M^2) h_1^{\bar{q}}(x_b, M^2) + (a \leftrightarrow b)}{\sum_q e_q^2 q(x_a, M^2) \bar{q}(x_b, M^2) + (a \leftrightarrow b)}, \quad (2)$$

where we have labeled by a, b the two incoming hadrons, the virtuality M^2 of the quark and antiquark distributions is the squared mass of the produced dilepton pair, and x_a, x_b, M^2 are related to the center-of-mass (c.m.) energy \sqrt{s} by $x_a x_b = M^2/s$. The partonic asymmetry a_{TT} is calculable in perturbative QCD [1] and in the dilepton center-of-mass frame reads

$$a_{TT} = \frac{\sin^2 \theta \cos 2\phi}{1 + \cos^2 \theta}, \quad (3)$$

where θ and ϕ are the polar and azimuthal angles of the lepton momentum with respect to the beam and the polarization axes, respectively. The value of a_{TT} varies between -1 and 1 .

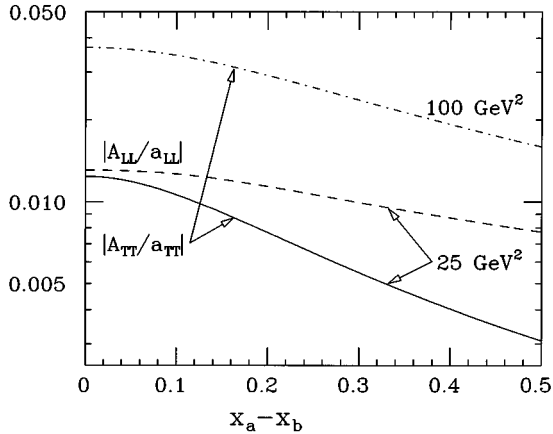


FIG. 2. The Drell-Yan double-spin transverse asymmetry $|A_{TT}/a_{TT}|$ for pp collisions as a function of $x_a - x_b$ (dot-dashed line: $M^2 = 100 \text{ GeV}^2$; solid line: $M^2 = 25 \text{ GeV}^2$). For comparison, the double longitudinal asymmetry $|A_{LL}/a_{LL}|$ is shown for $M^2 = 25 \text{ GeV}^2$ (dashed line). All curves are obtained with $\sqrt{s} = 100 \text{ GeV}$.

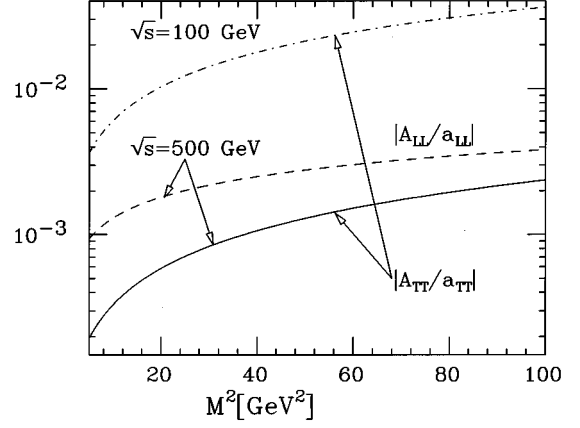


FIG. 3. Dependence on M^2 of the Drell-Yan double-spin transverse asymmetry for pp at $x_a - x_b = 0$ (dot-dashed line: $\sqrt{s} = 100 \text{ GeV}$; solid line: $\sqrt{s} = 500 \text{ GeV}$). The longitudinal counterpart is also plotted (dashed curve) for $\sqrt{s} = 500 \text{ GeV}$.

Another potentially interesting Drell-Yan process is the one mediated by a Z^0 , for which the transverse double-spin asymmetry reads [10]

$$A_{TT}^Z = a_{TT} \frac{\sum_q (V_q^2 - A_q^2) h_1^q(x_a, M^2) h_1^{\bar{q}}(x_b, M^2) + (a \leftrightarrow b)}{\sum_q (V_q^2 + A_q^2) q(x_a, M^2) \bar{q}(x_b, M^2) + (a \leftrightarrow b)}, \quad (4)$$

having denoted by V_q (A_q) the vector (axial) coupling of the flavor q to the Z^0 (see, for instance, [16]).

Let us come to our calculation. The only results we borrow from model computations are the approximate equalities

$$h_1^q(x, Q_0^2) \approx \Delta q(x, Q_0^2), \quad h_1^{\bar{q}}(x, Q_0^2) \approx \Delta \bar{q}(x, Q_0^2) \quad (5)$$

at a scale $Q_0^2 \leq 0.5 \text{ GeV}^2$. This is the starting point of the calculation. Instead of resorting to models, we use a global parametrization for the parton distributions. Since the equalities (5) are expected to be valid only at very small momentum transfer, we adopt the Glück-Reya-Vogelsang (GRV) [14] leading-order fit which provides the input polarized den-

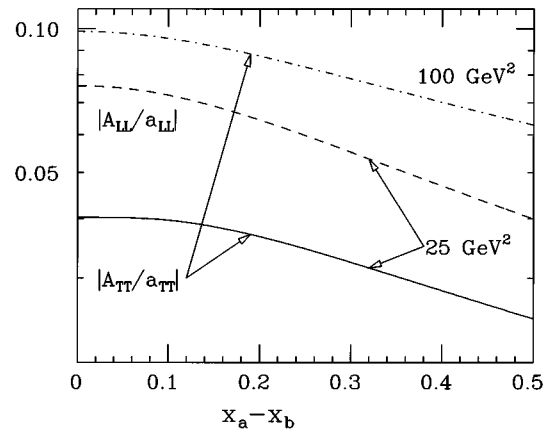


FIG. 4. Same as Fig. 2, for $\bar{p}p$ collisions.

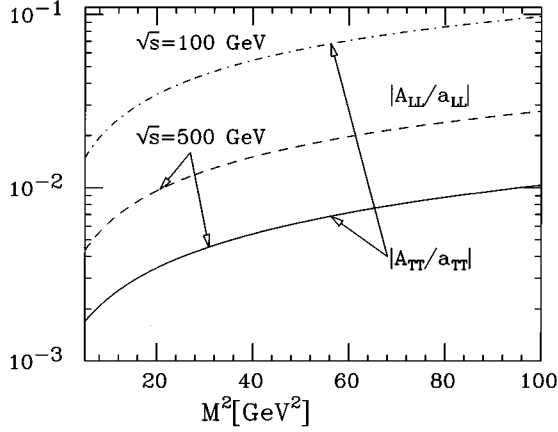


FIG. 5. Same as Fig. 3, for $\bar{p}p$ collisions.

sities $\Delta q, \Delta \bar{q}$ at $Q_0^2 = 0.23 \text{ GeV}^2$. Then the transverse distributions are evolved up to M^2 by solving the appropriate Altarelli-Parisi equation with the leading-order splitting function computed in [3].

For illustration we show in Fig. 1 the input and the evolved distributions for the dominant u, \bar{u} flavor (the situation is similar for the other flavors but we omit their plots for brevity). The difference between h_1^u and Δu at the scale $Q^2 = 25 \text{ GeV}^2$ in the low- x region is evident: h_1^u is smaller than Δu for $x \approx 10^{-2}$, whereas $h_1^{\bar{u}}$ is larger in absolute value than its longitudinal counterpart in the intermediate- x region and smaller at low x . This behavior of the parton distributions is responsible for the difference between the longitudinal and the transverse double-spin asymmetries, as we shall see below.

We present now the results for A_{TT} . Figure 2 displays $|A_{TT}/a_{TT}|$ as a function of M^2 for pp collisions with two different c.m. energies. Note that the sign of A_{TT}/a_{TT} is negative. In Fig. 3, $|A_{TT}/a_{TT}|$ is presented as a function of the Feynman variable $x_a - x_b$ for two M^2 values. In the kinematic range covered by the figures, which roughly corresponds to the experimentally accessible region, the transverse asymmetry is at most few percent. It is also a decreasing function of \sqrt{s} for fixed M^2 , and an increasing function of M^2 for fixed \sqrt{s} . Therefore, reaching high values of \sqrt{s} , such as those at which RHIC will operate, does not help getting a sizable asymmetry. On the other hand, since M^2 and \sqrt{s} are experimentally correlated, the relatively small c.m. energy of HERA \bar{N} ($\sqrt{s} \approx 50 \text{ GeV}$) allows exploring only the low-mass spectrum of dileptons ($M^2 \approx 20 \text{ GeV}^2$), where again the transverse asymmetry is expected to be small. Hence, the conclusion of a transverse asymmetry of order of 10^{-2} in the experimentally relevant kinematic region seems to be inescapable.

For comparison, in Figs. 2 and 3 we also display the double-spin longitudinal asymmetry $|A_{LL}/a_{LL}|$ obtained similarly from the GRV parton distributions. In the kinematic region shown in the figures the longitudinal asymme-

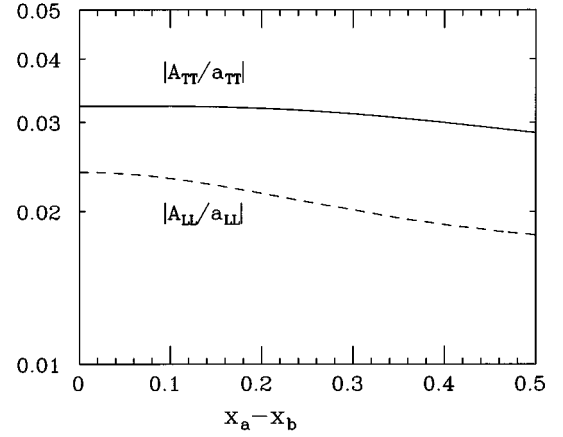


FIG. 6. The double-spin asymmetry for the Z^0 -mediated Drell-Yan process as a function of $x_a - x_b$ for $\sqrt{s} = 500 \text{ GeV}$ (solid line: the transverse asymmetry $|A_{TT}^Z/a_{TT}^Z|$; dashed line: the longitudinal asymmetry $|A_{LL}^Z/a_{LL}^Z|$).

try is larger than the transverse one as a consequence of the low- x behavior of the corresponding polarization distributions.

Analogous curves for the transverse asymmetry in the $\bar{p}p$ Drell-Yan process are plotted in Figs. 4 and 5. As we expected, the asymmetries are systematically larger than those in the pp case, but the exploration of this process seems to be beyond the present experimental possibilities.

In Fig. 6 the results for the Drell-Yan production via Z^0 exchange are presented. In this case, for kinematic reasons (remember that $x_a x_b = M^2/s$), the asymmetries reflect the behavior of the distributions in the intermediate- x region, where the transverse densities are larger in absolute value than the longitudinal ones. Thus, $|A_{TT}^Z/a_{TT}^Z|$ lies above its longitudinal counterpart, although it remains of order of few percent.

In conclusion, we presented a calculation of the double-spin transverse asymmetries in various Drell-Yan processes, based on the assumption (5) and on a global fit for the input distributions. The two novelties of our approach, which represent an improvement with respect to previous computations, are: (i) the equality (5) is strictly enforced only at a very small scale, that is the typical scale at which quark models describe the nucleon; (ii) the Q^2 evolution of h_1 is properly treated. The outcome of our calculation is similar to a previous confinement model result [12], namely, the transverse asymmetries are rather small, of order of 10^{-2} , in the accessible kinematic regions. An interesting finding is that $|A_{TT}|$ decreases with increasing center-of-mass energy. In order to maximize the asymmetry a delicate balance between \sqrt{s} and the dilepton-invariant mass M^2 should be found, although it appears unlikely to get values larger than few percent. As for the comparison with the longitudinal asymmetry, it is interesting to notice that we expect to have $|A_{TT}^Z|$ larger than $|A_{LL}^Z|$ in the Z^0 -mediated Drell-Yan process. All these predictions will hopefully be tested by future experiments.

- [1] J. P. Ralston and D. E. Soper, Nucl. Phys. **B152**, 109 (1979).
- [2] R. L. Jaffe and X. Ji, Phys. Rev. Lett. **67**, 552 (1991); Nucl. Phys. **B375**, 527 (1992).
- [3] X. Artru and M. Mekhfi, Z. Phys. C **45**, 669 (1990).
- [4] J. L. Cortes, B. Pire, and J. P. Ralston, Z. Phys. C **55**, 409 (1992).
- [5] R. L. Jaffe and X. Ji, Phys. Rev. Lett. **71**, 2547 (1993).
- [6] A. Yokosawa, in *Proceedings of the 11th International Symposium on High Energy Spin Physics*, Bloomington, IN, 1994 (AIP, New York, 1995).
- [7] M. Anselmino *et al.*, in *Future Physics at HERA*, Proceedings of the Workshop, Hamburg, Germany, edited by G. Ingelman (DESY, Hamburg, 1996), hep-ph/9608393.
- [8] X. Ji, Phys. Lett. B **284**, 137 (1992).
- [9] R. L. Jaffe and N. Saito, Phys. Lett. B **382**, 165 (1996).
- [10] J. Soffer, in *Frontiers of High Energy Spin Physics*, edited by T. Hasegawa *et al.* (Universal Academic, Tokyo, 1993); C. Bourrely and J. Soffer, Nucl. Phys. **B423**, 329 (1994).
- [11] C. Bourrely and J. Soffer, Nucl. Phys. **B445**, 341 (1995).
- [12] V. Barone, T. Calarco, and A. Drago, Phys. Lett. B **390**, 287 (1997).
- [13] V. Barone, Torino Report No. DFTT 68-96 (unpublished).
- [14] M. Glück, E. Reya, and W. Vogelsang, Phys. Lett. B **359**, 201 (1995).
- [15] O. Martin and A. Schäfer, Report No. hep-ph/9607470 (unpublished).
- [16] E. Leader and E. Predazzi, *An Introduction to Gauge Theories and Modern Particle Physics* (Cambridge University Press, Cambridge, England, 1996).