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Strong Spin-Torsion Interaction between Spinning Protons.

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Summary. — We consider the presence of the spin-torsion strong interaction in the proton-proton scattering at several GeV with the aim to see its significance in the anomalous behaviour shown by the scattering cross-section of polarized proton beams (*i.e* depending on whether they are parallel or oppositely polarized). Our conclusions seem consistent with experimental data.

PACS 11.10.Np – Gauge field theories.
PACS 13.85.Dz – Elastic scattering (energy > 10 GeV).
PACS 14 20.Ei – Protons.

1. – Introduction.

Spin is an important intrinsic property of an elementary particle, mass and spin being the two invariants of the Lie algebra of the Poincaré group. Spin has a basic role in the interactions between elementary particles, and moreover all fundamental interactions between particles are spin dependent such as strong and weak interactions. This includes gravitation also, spin-spin gravitational forces between particles becoming important in certain situations!

Einstein's gravity theory does not consider the particle spin in its formulation, only the energy contributing to the gravitational field. However gauging of the Poincaré group leads to the Einstein-Cartan theory of gravity which has the peculiar additional feature of a contact spin-spin interaction term (1). Gauge theories are generally presumed to eliminate contact interactions and other renormalizable interactions by introduction of gauge fields. Here we have on the contrary an example par excellence of a gauge theory inevitably giving rise to precisely such interactions! The spin torsion interaction is an inevitable feature of Poincaré and Lorentz gauge theories and also occurs in other non-Abelian gauge theories such as in supergravity models (2).

In a Riemann-Cartan space for instance the spin-torsion interaction (1) is given by the Lagrangian

(1) $$\mathscr{L} = (1/2)\, S^{kji} K_{ijk}\,,$$

where $S_{ijk} = -S_{jik}$ is the canonical spin-tensor and

(2) $$K_{ijk} = -Q_{ijk} - Q_{kij} + Q_{jki} = -K_{ikj}$$

is the contorsion tensor.

Q_{ijk} is the torsion tensor, being the skew-symmetrical part of the generalized affine connection $\Gamma^{k}{}_{ij}$. Thus

(3) $$Q_{ij}{}^{k} = \Gamma_{[ij]}{}^{k}\,,$$

where with the usual convention antisymmetrization is denoted by square brackets.

In the Einstein-Cartan field equations, the torsion is connected to the spin density tensor $J_{ij}{}^{k}$ (which also acts as a source term like T_{ij}) through the relations

(4) $$Q_{ij}{}^{k} = (8\pi G/c^{2})(J_{ij}{}^{k} - 1/2\,\delta_{i}{}^{k} J_{bj}{}^{b} - 1/2\,\delta_{j}{}^{k} J_{ib}{}^{b})\,.$$

The spin tensor is related to the $J_{ij}{}^{k}$ by

(5) $$S_{ij}{}^{k} = \int \mathrm{d}^{3}x \sqrt{-g}\, J_{ij}{}^{k}\,.$$

For Dirac particles, the spin is a totally antisymmetric tensor, so that we can write

(6) $$S^{ijk} = \eta^{ijk\rho} S_{\rho}\,,$$

where $\eta_{ijk\rho}$ is the completely antisymmetric symbol defined by $\eta_{0123} = (-\det g_{ik})^{1/2}$. S_{ρ} is the spin pseudovector.

(1) F. W. HEHL, P. VON DER HEYDE, G. D. KERLICK and J. M. NESTER: *Rev. Mod Phys.*, 48, 393 (1976).

(2) P. VAN NIEUWENHUIZEN: in *Spin, Torsion, Rotation and Supergravity*, edited by P. G. BERGMANN and V. DE SABBATA (Plenum Press, New York, N.Y., 1980), p. 227.

2. – Spin-torsion interaction in the generalized Dirac equation.

The interaction Lagrangian [3-5] as given by eq. (1) then contains only the axial-vector part of the torsion tensor and may thus be expressed as

$$\mathscr{L} = -S_k Q^k, \tag{7}$$

where the Q_k have been defined as

$$Q_k = c/2\, \eta_{k\nu\alpha} Q^{\nu\alpha}. \tag{8}$$

In the frame of the rest system of the particle (*i.e.* $S^k \equiv (0, \overline{S})$), the interaction energy between the spin $\overline{S}$ and the torsion $\overline{Q}$ can be written as

$$E = \mathscr{L} = -\overline{S} \cdot \overline{Q}. \tag{9}$$

This is noted to be formally analogous [3,4] to the interaction energy of a magnetic-dipole moment $\overline{\mu}$ in a constant magnetic field $\overline{H}$, *i.e.*

$$E = -\overline{\mu} \cdot \overline{H}. \tag{10}$$

For a spin density of $\overline{J}$, *i.e.* spin per unitary volume, the associated torsion is given by

$$\overline{Q} = 4\pi G \overline{J}/c^2, \quad \text{where} \quad \overline{J} = \overline{S}/V, \tag{11}$$

V being the volume containing the spin $\overline{S}$. The spin-torsion interaction Hamiltonian is then given by

$$H_{\rm ST} = (4\pi G \overline{J}/c^2)\, \overline{S}. \tag{12}$$

In general in a polarized medium (or target) with N aligned spins per unit volume, the torsion is given by

$$\overline{Q} = (4\pi G/c^2)\, \overline{S} N. \tag{13}$$

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(3) V. DE SABBATA and M. GASPERINI: *Lett Nuovo Cimento*, 27, 133 (1980).

(4) V. DE SABBATA and M. GASPERINI: in *Origin and Evolution of Galaxies*, edited by V. DE SABBATA (World Sci., Singapore, 1982), p. 181.

(5) V. DE SABBATA: in *Gravitational Measurements, Fundamental Metrology and Constants*, edited by V. DE SABBATA and V. MELNIKOV (Kluwer Acad Publ., The Netherlands, 1988), p. 115.

The torsion vanishes at every point where there is no net density of oriented (polarized) spinning particles, so that the spin torsion interaction is present when we have oriented intrinsic spins. If a constant torsion $\overline{Q}$ is introduced, each spinning particle has two possible states corresponding to spin aligned along or opposite to the torsion axis with an interaction spin-torsion energy of

$$U_0 = \pm \overline{S} \cdot \overline{Q} . \tag{14}$$

It turns out that this spin-torsion force is attractive for parallel spins (*i.e.* for pair of particles whose spins are parallel). The force is repulsive for pair of particles with antiparallel spins, *i.e.* when spins are polarized in opposite directions. The attractive force between parallel spins is in contrast to the repulsive force between like charges. This would imply that, as we shall see later (see sect. 3), a spinning particle in a spin-polarized medium or target would be antiscreening rather than screened like charged particles in a charge polarized medium, that is the spin-torsion coupling constant increases with distance (like in a non-Abelian gauge theory), implying thus that spin gauge theory is asymptotically free, the coupling tending to vanish at sufficiently high energy.

Thus the generalized Dirac equation [1,6,7] in a Riemann-Cartan manifold following from a Lagrangian minimally coupled to the metric and to the torsion is of the form

$$i\gamma^a \psi_{,a} + i/4\, K_{abc}\, \gamma^{[a} \gamma^b \gamma^{c]} \psi - m\psi \tag{15}$$

(the Dirac spinor couples only with to the antisymmetric part of the torsion tensor $K_{[abc]} = - Q_{[abc]}$, because of the totally antisymmetric product of Dirac matrices in eq. (15)). In the absence of torsion, the Dirac equation in a curved space could be obtained directly from the special relativistic equation by simply replacing the partial derivative with the covariant one. The Dirac equation (15) can also be reduced to a nonlinear spinor equation (see refs. [6-8]) of the type

$$i\gamma^a \psi_{,a} - 3/8\, \chi \overline{\psi} \gamma^5 \gamma_a \psi \gamma^5 \gamma^a \psi - m\psi = 0 , \tag{16}$$

where $\overline{\psi} \gamma^5 \gamma_a \psi = J^5{}_a$ is the axial-vector spinor current.

It is important to note that in the case of massless spinor fields satisfying the Weyl conditions $1/2(1 + \gamma^5)\psi = \psi$, defining two-component spinors, the nonlinear correction in eq. (16) induced by torsion is identically vanishing [8], and eq. (16) simply becomes $\gamma^k \psi_{,k} = 0$. The only difference induced by torsion in respect of the

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(6) C. SIVARAM and K. P. SINHA: *Lett. Nuovo Cimento*, 13, 357 (1975).

(7) C. SIVARAM and K. P. SINHA: *Phys. Rep.*, 51, 111 (1979).

(8) V. DE SABBATA and M. GASPERINI: *Introduction to Gravitation* (World Sci., Singapore, 1985).

usual general relativistic Dirac equation is represented by the spin torsion contact interaction $\propto J^5{}_k J^{5k}$. This contact interaction takes place when spinning particle collide and interpenetrate and disappears outside spinning bodies.

3. – Propagating torsion.

However, the torsion field can be made to propagate by considering interaction between torsion and a spinor field and expressing the axial part of the torsion tensor [8-10] in terms of a pseudoscalar potential Φ as

$$Q_\mu = \partial_\mu \Phi . \tag{17}$$

The variation of the generalized Dirac action with respect to ψ, $\overline{\psi}$ and Φ then gives the equation [8,11]

$$i\gamma_\mu \psi_{,\mu} - 3/2\, \partial_\mu \Phi \gamma^5 \gamma^\mu \psi - m\psi = 0 \tag{18}$$

and

$$\Phi^{,\mu}{}_{,\mu} = 1/2\, \chi(\overline{\psi}\gamma^5 \gamma^\mu \psi)_{,\mu} . \tag{19}$$

We then have a propagating torsion field, because its potential satisfies a wave equation (19).

Considering the limit of static spin source, when $\overline{\psi}\gamma^5 \gamma^\mu \psi \approx 0$ and $\overline{J}^5 \approx \overline{\Sigma}$ is the spin density vector of the source, (19) becomes

$$\nabla^2 \Phi = 1/2\, \chi \overline{\nabla} \cdot \overline{\Sigma} . \tag{20}$$

The total spin

$$\overline{S} = \int \mathrm{d}^3 x\, \overline{\Sigma}(x) \tag{21}$$

vanishes if there is no preferred direction for spin alignment. If $S \neq 0$, as spins are at least partially polarized in some preferred direction, a dipolar torsion field is produced

$$\overline{Q} = \overline{\nabla} \Phi = (G/c^3 r^5)[\overline{S} r^2 - 3\overline{x}(\overline{S} \cdot \overline{x})] . \tag{22}$$

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(9) V. DE SABBATA and M. GASPERINI: *Phys Rev. D*, **23**, 2116 (1981); *Lett Nuovo Cimento*, **30**, 503 (1981).

(10) C. SIVARAM and K. P. SINHA: *Phys. Rev. D*, **16**, 1975 (1977).

There are other ways of getting a propagating spin-torsion field interaction. For instance in the Poincaré gauge-theoretic approach we consider a group of transformations in the local tangent space [7,11] where spinor fields transform as

$$\psi(x) \rightarrow \psi'(x) = \exp[1/2\beta_{\mu\nu}(x)\Omega^{\mu\nu}]\psi(x)\,. \tag{23}$$

Unlike in the Poincaré gauge theory, in a gauge theory involving a local internal symmetry group, invariance of Lagrangian density also implies invariance of the action. However the $\beta_{\mu\nu}$ can be chosen as [11,12]

$$1/6\,\eta^{ijkl}\,\partial_i\beta_{jk}(x) = \partial^l \Lambda(x)\,. \tag{24}$$

The usual Dirac Lagrangian is not invariant under transformations (23) and (24) but becomes invariant with the covariant derivative chosen as

$$\gamma^i D_i \psi_a = \gamma^i (J_a{}^b \partial_i + g/4\,\eta_{ijkl}\Omega_a{}^{jkb} B^l)\psi_b = \gamma^i(\partial_i + 3g/4\,\gamma^5 B_i)\psi_a\,, \tag{25}$$

where g is the usual gauge coupling constant. $B_i(x)$ is a massless vector and transforms as

$$B_i(x) \rightarrow B_i'(x') + 2/3\,\beta_{ij}(x)B^j(x) - 1/g\,\partial_i\Lambda(x)\,. \tag{26}$$

$B_i(x)$ also satisfies as usual the Lorentz gauge $\partial^i B_i(x) = 0$ and has a kinetic term of the form

$$-1/2\,\partial_i B_j \partial^i B^j - 3/16\,g^2(B_i B)^2\,. \tag{27}$$

The total Lagrangian has the form

$$\mathcal{L} = -\bar{\psi}(\gamma^i\partial_i + m)\psi - 1/2\,\partial_i B_j \partial^i B^j - 3/4\,g\bar{\psi}\gamma^i\gamma^5\psi B_i - 3/16\,g^2(B_i B^i)^2\,. \tag{28}$$

Thus analogous to eq. (16) we again set an axial spinor current. In the above formalism we have not use vierbeins in defining the covariant derivative. But because of the choice of eq. (24) for $\beta_{jk}(x)$ we also are able to ensure invariance of both the Lagrangian density and the action, like in theories with internal gauge symmetries. The interaction Lagrangian with the axial spinor field has the form

$$L_{\text{int}} = -g\eta^{ijkl}\,\partial_i\psi_j\psi_k B_l - 1/2\,g^2(B^i B_i \psi^j\psi_j - \psi^i B_i \psi^j B_j)\,. \tag{29}$$

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(11) C. SIVARAM and K. P. SINHA: *Lett. Nuovo Cimento*, **9**, 704 (1974).
(12) T. PRADHON and S. NAIK: *J Phys. A*, **14**, 2795 (1981).

This gives rise to a two-body spin-spin force which reduces to an expression like eq. (22) in the nonrelativistic case, *i.e.*

$$V_{12}(r) = -g^2/2r[\overline{\sigma}_1\cdot\overline{\sigma}_2+(\overline{\sigma}_1\cdot\overline{r})(\overline{\sigma}_2\cdot\overline{r})/r^2]. \tag{30}$$

This force is attractive for parallel spins and repulsive for antiparallel spins. Also a term like $i\bar{\psi}\gamma^5\gamma^i g_i\psi$ in the Dirac Lagrangian would in the slow motion limit imply an interaction in a gravitational field with acceleration «g'» of $\approx \hbar c\sigma\cdot g'$, giving rise to energy level splitting of $\approx 2\hbar c^{-1}g'$. The above kind of interaction term would violated P invariance. Thus the existence of a spin-torsion interaction as given by eqs. (11)-(14) is an inevitable feature of the above gauge-invariant formalism. Two spinning particles would experience such an interaction.

4. – Spin-torsion interaction in a strong-gravity field.

The above formalism can be carried over into the context of strong gravity theory which is the appropriate framework for the case of strongly interacting particles (13). In the strong-gravity picture the gravitational interaction of hadrons at distance scales of the order of the strong interaction (*i.e.* ≈ 0.5 fm) are dominated by massive tensor (*i.e.* spin-two) mesons. Such strongly interacting spin-two fields when self-coupled will lead to Einstein-like equation (7,14,15) for strong gravity with the Newtonian constant G replaced by strong coupling constant (or strong gravity constant) $K_f = 10^{38}\,G$. The solutions of Einstein's field equations as well as interactions involving spin and torsion can be carried over, *mutatis mutandis* into the strong-gravity regime. Such an approach gives a good description of many of the features of strongly interacting particles (7,14). Thus for two spinning protons, the spin-torsion interaction energy in the strong-gravity field becomes (see eq. (11), (12) and (13)):

$$H_{\text{S-T}} = 4\pi/c^2 K_f \hbar/(\hbar/m_p c)^3 N\hbar/2 \approx 4\pi/c^2 K_f (m_p c^3/\hbar^2)\hbar \approx 4\pi K_f m_p{}^3 c/\hbar, \tag{31}$$

where we have used for the spin density J, the spin of the protons ($\hbar$) averaged over the Compton radius cubed and $S=\hbar/2$, $N=2$. Using for $K_f \approx 6.7\cdot 10^{30}$ c.g.s. (ref. (11)) we set $H_{\text{S-T}}\approx 10\,\text{GeV}$, *i.e.* the strong spin-torsion coupling energy between two spinning protons is about 10 GeV. So the effects of the short-range (*i.e.* contact) strong spin-torsion interaction would be expected to be seen for colliding protons at about this energy (~ 10 GeV) when they are separated by

(13) C. ISHAM, A. SALAM and J. STRATHDEE: *Phys Rev D*, **3**, 867 (1971).
(14) C. SIVARAM and K. P. SINHA: *Phys Lett. B*, **60**, 181 (1976).
(15) V. DE SABBATA and P. RIZZATI: *Lett. Nuovo Cimento*, **20**, 525 (1977).

$\sim \hbar/m_p c \sim 0.1\,\text{fm}$. Further, as we pointed out, this spin force is *attractive* for proton spins which are parallel, *i.e.* for *polarized* spins and *repulsive* for *antiparallel* spins. From eq. (14), there would be a difference of a factor two in the Hamiltonians between the states with spins parallel and antiparallel. For antiparallel spin the spin force between two protons would be repulsive. On the contrary, for protons whose spins are parallel or polarized in the same direction, the attractive spin-spin force between them would make them more likely to collide than when they are antiparallel in which case the additional spin-spin repulsive force would prevent them from colliding. Thus the probability of collisions at around 10 GeV considerably increases when the spins are parallel than when they are antiparallel. As the interaction cross-section or transition rate is proportional to the square of the Hamiltonian this would imply a maximum factor of four in the ratio of cross-sections (as there is a difference of a factor two in the Hamiltonians as noted above) for spins parallel and antiparallel. We would like make this more precise as follows: at about proton kinetic energy (c.m.s.) of 10 GeV, the spin-torsion interaction energy $\overline{S} \cdot \overline{Q}$ is of the same order as the k.e., *i.e.* the total Hamiltonian $\approx 2\overline{S} \cdot \overline{Q}$. For antiparallel spins, (no orientation) $N = 0$ in eq. (13), so that the Hamiltonian is just $\approx 10\,\text{GeV} \approx S \cdot Q$ and then the ratio is two. The cross-section which would be the square of this would then be four. This is the maximum ratio possible corresponding to the two extreme limits. Again we would expect the cross-sections for the spin effects to rise with the square of energy. This can be seen as follows: the strong-gravity coupling K_f is usually of order $\sim c\hbar/m^2$ and may be therefore expected to scale at high momenta like $\sim 1/p^2$. Again the interaction volume can be expected to decrease like $(\hbar/p)^3$, *i.e.* $\sim 1/p^3$, so that eq. (31) would imply $H_{\text{S-T}}$ going as p, which would in turn suggest the cross-section scaling as p^2. Again we would recall that the usual spin torsion contact interaction which occurs in eqs. (15) and (16) and behaves like the Fermi weak interaction of the $(V - A)$ type has a cross-section rising with energy as E^2 (ref. ([16])).

As we noted in connection with eq. (16), in the case of massless spinor fields (for which the Weyl conditions are satisfied) the nonlinear correction introduced by the spin-torsion interaction vanishes. At sufficiently high energy of the colliding protons, they may behave like massless particles (this also holds for the constituent quarks), so that the spin interaction between them would tend to vanish. We have also pointed out in this connection that the effective coupling constant for the spin-torsion interaction would tend to become smaller at higher energy scaling roughly as $1/p^2$ and vanish at sufficiently high energy owing to the asymptotically free nature of the spin gauge theory. So that the spin effects, which are most marked at some 10 GeV, would tend to become unimportant at sufficiently larger energies. Again at sufficiently high energies the quarks

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([16]) C. SIVARAM: *Bull Astr Ind.*, 13, 339 (1985) (Gravity Foundation Essay, 1983).

constituting the protons would tend to become free and essentially behave like massless particles. So the volume factor in eq. (31) would tend to stop contracting at about ($\sim 1/20$ fm, the typical quark size) some few tens of GeV, while the coupling constant K_f would tend to continue falling like $1/p^2$, so that the cross-section for the spin interactions would fall off with energy (rather than rise as at lower energies) after some particular value of the energy. One would therefore not expect the spin effects to be important at very high energy (say > 100 GeV).

At energies of a few tens of GeV as far as the interaction term in eqs. (16) and (18) (which is *P asymmetric*) is concerned the u-quarks behave like left-handed particles (analogous to electron in β-decay) so that as the proton is made up of two u-quarks and one d-quark one would expect a 2:1 asymmetry in favour of left-handed helicity in proton-proton scattering at a few tens of GeV.

As indicated earlier the interaction term of type $\psi\gamma^5\gamma^i g_i\psi$ which violates left-right P symmetry would give rise to energy level splitting of $\sim 2\hbar c^{-1} g$, g being the effective acceleration. As the effective acceleration in the strong gravity interaction is $\sim c/(\hbar/mc^2) \sim 3\cdot 10^{34}\,\mathrm{cm\,s^{-2}}$, this would imply a P asymmetry in energy levels of ~ 30 GeV (distance of $\sim 1/20$ fm). As photons and gluons have spin, (being vector fields) they would also couple to the axial gauge field $B_i(x)$ introduced in eqs. (26)-(28). The interaction Lagrangian for the gluon field $G_k{}^a (a = 1, \ldots, 8)$ with B_i given by using the covariant Lagrangian derivative

$$D_i G_k{}^a = \partial_i G_k{}^a - ig/4\, \eta_{ijkq} \Omega^{jq}{}_{bc} B^b G^{ac} \tag{32}$$

in the gluon Lagrangian

$$L_g \approx -1/4\, (\partial_i G_j{}^a - \partial_j G_i{}^a)(\partial^i G_a{}^j - \partial^j G_a{}^i) \tag{33}$$

is

$$L_g \approx -g\, \eta^{ijpq} \partial_i G_j{}^a G_{pa} B_q - 1/2\, g^2 (B^i B_i G^{ja} G_{ja} - G^{ia} B_i G^j{}_a B_j)\,. \tag{34}$$

5. – Concluding remarks.

One has analogous expressions to eqs. (33) and (34) for the interaction between the axial gauge field and the photon field $A_i(x)$. The coupling of the photon field to the torsion gauge field can give rise to a spin force between polarized beams of photons [17-19]. In fact spin-dependent forces between

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(17) V. DE SABBATA and M. GASPERINI: *Nukleonika*, 25, 1373 (1980).
(18) V. DE SABBATA and M. GASPERINI: *Phys. Lett A*, 77, 300 (1980).
(19) V. DE SABBATA and M. GASPERINI: *Lett. Nuovo Cimento*, 28, 181, (1980), 30, 193, 363 (1981).

circularly polarized laser beams have been observed in alkali vapour ([20]). Similar forces must exist (from eqs. (33) and (34)) between gluons and the torsion field and between quarks and gluons for polarized colliding proton beams. In the case of photon beams it was hypothesized that exchange of polarized atoms between the beams could mediate these spin-dependent interactions. Now in the presence of the strong torsion interaction there could be flavour mixing between quarks via currents like $J_{\iota 5}{}^{a} = \overline{u}_{a} \gamma_{\iota} \gamma_{5} u^{a}$ this could give rise to flavour oscillations over a length scale $l = 2\pi/\Delta E$ (ΔE = energy difference between aligned and nonaligned spins in torsion field), l being expressed as $l \geqslant c^{3}/2\pi K_{f} \hbar \rho \delta^{2}$, where $\delta^{2} \geqslant k_{1} - k_{2}$ and $l \approx 10^{-13}$ cm for the strong-gravity field. These flavour oscillations could lead to oscillatory behaviour in the cross-sections which are energy dependent (oscillations over energy scales $\sim c\hbar/l \approx 20$ GeV). Moreover as the cross-sections are energy dependent, energy differenced ΔE in the torsion field which would have oscillatory behaviour would be reflected in the oscillatory behaviour of the cross-section on these scales.

Recent experiments ([21,22]) involving collisions between high-energy polarized proton beams show anomalous behaviour in the cross-sections depending on the orientation of the spins. For instance, the cross-section for beams parallel, *i.e.* polarized in the same direction, show dramatic increase (up to a factor of four) for the probability of collisions as compared to the case of antiparallel or oppositely polarized beams at around $(8-12)$ GeV. The cross-sections for spin-dependent interactions also seem to show increase with p^2 at higher energies. There is a preferable scattering to the left at energies around 20 GeV. The increase in cross-section for parallel spins is observed to decrease at still higher energies. There is also evidence for oscillatory behaviour, so many of the above-observed experimental features in polarized colliding proton beams at several GeV, which appear puzzling from the conventional view of strong interactions, are not inconsistent with the theoretical conclusions regarding the behaviour pointed out above on the basis of the existence of the strong spin-torsion interaction between the spinning protons.

The universality of such an interaction is an inevitable feature of all spin gauge theories and would lead to the phenomena described earlier.

([20]) A. C. TAM and W. HAPPER: *Phys. Rev. Lett* , 38, 278 (1977).

([21]) E. A. CROSBIE, L. G. RATNER, P. F. SCHULTZ, J. R. O'FALLON, D. G. CRABB, R. C. FERNOW, P. H. HANSEN, A. D. KRISCH, A. A. SALTHOUSE, B. SANDLER, T. SHIMA, K. M. TERWILLIGER, N. L. KARMAKAR, S. L. LINN, A. PERLMUTTER and P. KYBERD: *Phys Rev. D*, 23, 600 (1981).

([22]) G. R. COURT, D. G. CRABB, I. GIALAS, F. Z. KHIARI, A. D. KRISCH, A. M. T. LIN, R. S. RAYMOND, R. R. RAYLMAN, T. ROSER, K. M. TERWILLIGER, K. A. BROWN, L. G. RATNER, D. C. PEASLEE, P. R. CAMERON, J. R. O'FALLON, T. S. BHATIA, L. C. NORTHDIFFE and M. SIMONIUS: *Phys Rev Lett.*, 57, 507 (1986).

RIASSUNTO

Si considera la presenza dell'interazione forte spin-torsione nello scattering protone-protone alle energie di diversi GeV con l'intento di vedere qual'è la sua incidenza nel comportamento anomalo mostrato nella sezione d'urto di scattering di fasci di protoni polarizzati (a seconda cioè che siano polarizzati parallelamente o antiparallelamente). I risultati dei calcoli sembrano consistenti con i dati sperimentali.

Сильное спин-торсионное взаимодействие между вращающимся протонами.

Резюме (*) — Мы рассматриваем наличие сильного спин-торсионного взаимодействия в протон-протонном рассеянии при нескольких ГэВ с целью определить его значимость в аномальном поведении, обнаруженном в поперечном сечении рассеяния поляризованных протонных пучков (в зависимости от того поляризованы они параллельно или антипараллельно) Результаты вычислений удовлетворительно согласуются с экспериментальными данными

(*) *Переведено редакцией.*