SEARCH FOR QUARK COMPOSITENESS WITH POLARIZED BEAMS AT RHIC

J.M. Virey

Centre de Physique Théorique*, C.N.R.S. - Luminy, Case 907
F-13288 Marseille Cedex 9, France

and

Université de Provence, Marseille, France

Abstract

Around 1999, thanks to the RHIC Spin Collaboration (RSC), the Relativistic Heavy Ion Collider (RHIC) will be used as a polarized proton-proton collider. A new handed interaction between quark subconstituents, which could explain the excess of large $E_T$ jet found by the CDF collaboration, could be at the origin of some small parity violating effects in one-jet inclusive production. Using spin asymmetries it is possible, at RHIC, to disentangle this new effect from the Standard Model prediction due to QCD-ElectroWeak interferences.

*Unité Propre de Recherche 7061
1 Moniteur CIES and allocataire MESR
email : virey@cpt.univ-mrs.fr
1 Introduction

The idea of compositeness has been introduced in the hope of solving some problems of the Standard Model (SM). The phenomenological approach is to consider a new "contact" interaction between quark subconstituents, which is normalized to a certain compositeness scale $\Lambda$. This is represented by the following effective lagrangian [1] :

$$\mathcal{L}_{qqqq} = \epsilon \frac{g^2}{8\Lambda^2} \bar{\Psi} \gamma_{\mu}(1 - \eta\gamma_5)\Psi \bar{\Psi} \gamma^{\mu}(1 - \eta\gamma_5)\Psi$$  

(1)

where $\Psi$ is a quark doublet, $\epsilon$ is a sign and $\eta$ can take the values $\pm 1$ or 0. $g$ is a new strong coupling constant normalized usually to $g^2(\Lambda) = 4\pi$.

Working at Fermilab at the Tevatron $\bar{p} - p$ collider with $\sqrt{s} = 1.8$ TeV, the CDF collaboration has found an excess of events at high $E_T$ in the inclusive one-jet cross section [2]. This can be interpreted as a manifestation of compositeness for a scale of order $\Lambda \sim 1.6$ TeV. In fact we will take this value as the actual limit.

The expression (eq. [1]) is rather general. In particular, there is no reason to assume that the new interaction is a parity conserving (PC) one. On the contrary, it has been advocated for some time [1] that parity violation (PV) could be present ($\eta \neq 0$).

On the other hand, it is well-known from deep-inelastic scattering or $e^+e^-$ experiments, that the measurement of some spin asymmetries gives a direct way to pin down a PV interaction.

It is then tempting to propose the search for an effect which is absent in strong processes, like the production of jets, as long as these processes are solely described in the framework of QCD which is a parity conserving theory. An analysis similar to the one presented here can be found in [3].

The RHIC Spin Collaboration (RSC) [4] has recently proposed to run the Brookhaven Relativistic Heavy Ion Collider (RHIC) in the $pp$ mode, with longitudinally (or transversely) polarized beams. The degree of polarization of the beam will be as high as 70%, with a high luminosity of $\mathcal{L} = 2.10^{32} cm^{-2}.s^{-1}$ at a center-of-mass energy up to 500 GeV.

To build a PV asymmetry one single polarized beam is sufficient. However, our recent experience [3] taught us that a larger effect can be obtained by using both polarized colliding beams which are available at RHIC. One can define the double helicity PV asymmetry :

$$A_{LL}^{PV} = \frac{d\sigma_{(-)(-)} - d\sigma_{(+)(+)} - d\sigma_{(-)(-)} + d\sigma_{(+)(+)} }{d\sigma_{(-)(-)} + d\sigma_{(+)(+)}}$$  

(2)

where the signs $\pm$ refer to the helicities of the colliding protons.

A whole set of measurements of the large Standard PC and PV asymmetries [5] should allow to isolate with very good precision the polarized distribution functions of the various partons (quarks and gluons) in a polarized proton (see refs. [6,7]) and, in the meantime, to perform some polarization tests of the Standard Model (for reviews on spin physics at future hadronic colliders one can consult refs. [8,9]).

Let us focus now on the production of a single jet and concentrate on the high $E_T$ region where quark-quark elastic scattering is the dominant process and where an effect due to compositeness has some chance to be observed [3,10]. At RHIC it corresponds to the region $60 < E_T < 120$ GeV.
We have to remark that we search for some small effects, since we want to measure an asymmetry which is zero according to QCD (QCD is PC!), then the QCD-Electroweak interference terms [11] are no more negligible. So the calculations described below take into account all the (lowest order) relevant terms: QCD + Electroweak (EW) + Contact Terms (CT) which are to be added coherently.

2 Parity violating subprocesses for the one-jet inclusive production

If one ignores the contribution of the antiquarks, which is marginal in our \( E_T \) range, and restricts to the main channels \( q_i q_i \rightarrow q_i q_i \) and \( q_i q_j \rightarrow q_i q_j \ (i \neq j) \) one gets in short:

\[
A_{LL}^{PV} \cdot d\sigma \simeq \sum_{ij} \sum_{\alpha,\beta} \int \left( T_{\alpha,\beta}^-(i,j) - T_{\alpha,\beta}^+(i,j) \right) \left[ q_i(x_a)\Delta q_j(x_b) + \Delta q_i(x_a)q_j(x_b) + (i \leftrightarrow j) \right] \quad (3)
\]

where \( T_{\alpha,\beta}^\lambda \) denotes the matrix element squared with \( \alpha \) boson and \( \beta \) boson exchanges, or with one exchange process replaced by a contact interaction, and where we have introduced as usual the polarized quark distributions: \( \Delta q_i(x,Q^2) = q_{i+} - q_{i-}, \ q_{i\pm}(x,Q^2) \) being the distributions of the polarized quark of flavor \( i \), either with helicity parallel (+) or antiparallel (-) to the parent proton helicity. Concerning the QCD contribution to \( d\sigma \), we take also into account the antiquarks and also \( q(\bar{q})g \) and \( gg \) scattering although these subprocesses are not dominant in the high \( E_T \) region we consider.

For the scale \( Q^2 \), we have taken \( Q^2 = E_T^2 \) after having checked that changing this value between \( E_T^2/4 \) and \( 4 E_T^2 \) has a very small influence on our results on \( A_{LL}^{PV} \).

• Standard QCD-Electroweak interference effects

At RHIC, a very important parameter is the high luminosity: we obtain indeed an integrated luminosity \( L_1 = \int \mathcal{L} dt = 800 \, pb^{-1} \) after a few months of run. In the following, we will call \( L_2 \) the luminosity giving four times this sample of events. We have integrated over a pseudorapidity interval \( \Delta \eta^* = 1 \) centered at \( \eta^* = 0 \), and also over an \( E_T \) bin of 10 GeV. The error bars of the figures are obtained in this context.

Concerning the influence of QCD-EW interference terms on \( A_{LL}^{PV} \), we have already noticed in [3] that more than 90% of the effect comes both from the interference terms \( T_{gZ} \) between the gluon and \( Z^0 \) (identical quarks) and from the terms \( T_{gW} \) between the gluon and \( W \) (quarks of different flavors).

We give in Fig.1 the asymmetry \( A_{LL}^{PV} \) in one-jet production at RHIC which is expected from purely QCD-EW interference terms. The correct expressions for the \( T_{\alpha,\beta} \)'s can be found in ref.[6]. We have used various sets of polarized distributions, some quite old, like BRST [8], CN1 [12] or CN2 [13], and some recent ones which give better fits to the new polarized DIS data: BS [14], GS.a,b,c [15] and GRV.s,v [16]. Since these latter distributions provide the two extreme cases on \( A_{LL}^{PV} \) we will keep only these ones in the following.

We see that \( A_{LL}^{PV} \) remains small, at most 4% at \( E_T = 100 \, \text{GeV} \) but it is measurable with the sensitivity available at RHIC. Indeed it lies, with \( L_1 \), at 2\( \sigma \) above zero with GRV or GS distributions and 4\( \sigma \) with BS. Finally, the rise of \( A_{LL}^{PV} \) with \( E_T \) is due to the increasing importance of quark-quark scattering relatively to other terms involving gluons.
• Interference between Contact and Standard amplitudes

For the calculation we take all the tree-level diagrams with gluons, W, Z°, photons exchange and contact term. We have added all the terms, involving quarks or antiquarks, dominant or not. The main contribution comes from the interference between gluon and contact term, (due to color rules only identical quark are involved):

\[ T_{g,CT}^{\lambda_1,\lambda_2}(i, i) = \frac{8}{9} \alpha_s \epsilon \Lambda^2 (1 - \eta\lambda_1)(1 - \eta\lambda_2) \left( \frac{s^2}{t} + \frac{s^2}{u} \right) \]  

(4)

Since \( t \) and \( u \) are negative, \( \epsilon = -1 (+1) \) corresponds to constructive (destructive) interference [1,3], and we see that the parameter governing the sign of \( A_{PV}^{LL} \) is the sign of the product \( \epsilon\eta \) (see eq.(3)).

3 Discussion and results

If we interpret the CDF results as a manifestation of quark substructure for a scale \( \Lambda = 1.6 \) TeV and want to see the effects of the contact interaction at this scale on \( A_{PV}^{LL} \), we obtain in Fig. 2 the results of our complete calculation including all terms. The expected Standard asymmetry is shown for comparison. We have chosen the BS parametrization for illustration. One can see that, at RHIC, even with the integrated luminosity \( L_1 \), it is very easy to separate the Standard from the Non-Standard cases, since there is a 3\( \sigma \) effect with \( L_1 \). With GS or GRV distributions, the magnitudes of the asymmetries are reduced but the effect is still spectacular.

Now, if we ignore the CDF results and choose \( \Lambda = 2 \) TeV (Fig. 3), we see that, with \( L_1 \), there is still a 2\( \sigma \) difference (4\( \sigma \) with \( L_2 \)) between the Standard and Non-Standard asymmetries, especially for values of \( E_T \) above 80 GeV.

In Fig. 4 we display again \( A_{PV}^{LL} \) with \( \Lambda = 2 \) TeV, but now calculated using the two extreme choices, BS and GS distributions. The clearest result is that, in spite of the present uncertainty due to the imperfect knowledge of the polarized quark distributions, a value for \( A_{PV}^{LL} \) close to zero at large \( E_T \) is the sign of the presence of Non-Standard physics (namely either a left-handed contact interaction with destructive interference or a right-handed one with constructive interference). Indeed, with \( L_2 \), the two close BS and GS curves stand at 3\( \sigma \) from the smaller QCD-EW asymmetry which corresponds to the GS parametrization. The situation is less spectacular in the case where \( \epsilon\eta = -1 \) but it is still interesting.

Finally, we have tried to determine if the information from the measurement of \( A_{PV}^{LL} \) could compete with the bounds on \( \Lambda \) one could reach in the future at the Tevatron (with unpolarized beams). Following the strategy of refs. [1,17], we have calculated \( d\sigma (\text{QCD}+\text{CT}) \) in \( pp \) collisions at \( \sqrt{s} = 1.8 \) TeV demanding a 100% deviation from the QCD prediction at large \( E_T \) (with at least 10 QCD events). This crude strategy gives amazingly exactly the same result as the sophisticated CDF study. With an integrated luminosity of 100 \( pb^{-1} \) we expect a limit of \( \Lambda > 2 \) TeV at the Tevatron.

Requiring \( A_{PV}^{LL} = A_{SM} \pm \delta A \) where \( \delta A \) is the statistical error, we obtain at RHIC the following 95% C.L. limits : with \( L_1 \), for any distributions : \( \Lambda \sim 2.0 \) TeV; and with \( L_2 \), depending on the distributions : \( \Lambda \sim 2.7 - 3.0 \) TeV.

We see that an increase of the luminosity would increase considerably the limits on the compositeness scale. Consequently it appears that the luminosity is a key factor for the polarized analysis.
4 Conclusion

It has been stressed for some time that polarization at hadronic colliders should improve their potential capabilities [8,9], in particular in the search for New Physics if the energy is as large as the LHC energy (see e.g. [18]). We have seen here that, in spite of its lower energy, the RHIC collider, running in the \(pp\) mode, could compete with the Tevatron, thanks to the polarization and also to the high luminosity.

Furthermore, we have shown in a recent paper [19] that a hadrophilic \(Z'\) [20,21] could induce some visible effects on \(A_{LL}^{PV}\) in the inclusive one-jet production.

Finally, if the excess of events observed by CDF is due to quark compositeness, then RHIC will not be a tool for discovery but rather for analysis since it can provide unique information about the chirality structure of the new interaction.

Acknowledgments

I wish to thank Pierre Taxil for his collaboration. I am indebted to C. Benchouk, C. Bourrely, P. Chiappetta, M.C. Cousinou, A. Fiandrino, M. Perrottet and J. Soffer for discussions, help and comments, and to T. Gehrmann and W.J. Stirling for providing me some computer program about the GS distributions and to W. Vogelsang for the GRV one’s.

[1] E. Eichten, K. Lane and M. Peskin, Phys. Rev. Lett. 50, 811 (1983), E. Eichten, et al., Rev. Mod. Phys. 56 (1984) 579.
[2] F. Abe & al. (CDF Collaboration), FNAL-PUB-96/20-E; A. Goshaw in these proceedings.
[3] P. Taxil and J.M Virey, Phys. Lett. B364 181 (1995)
[4] RHIC Spin Collaboration (RSC), Letter of intent, April 1991 and RSC (STAR/PHENIX) letter of intent update, August 1992.
[5] G. Bunce et al., Polarized protons at RHIC, Particle World, 3, 1 (1992).
[6] C. Bourrely, J. Ph. Guillet and J. Soffer, Nucl. Phys. B361, 72 (1991).
[7] C. Bourrely, and J. Soffer, Nucl. Phys. B423, 329 (1994).
[8] C. Bourrely, J. Soffer, F.M. Renard and P. Taxil, Phys. Reports, 177, 319 (1989).
[9] P. Taxil, Riv. Nuovo Cimento, Vol. 16, No. 11 (1993).
[10] M. Tannenbaum, in Polarized Collider Workshop, J. Collins, S.F. Heppelmann and R.W. Robinett eds, AIP Conf. Proceedings 223, AIP, New York, 1990, p. 201.
[11] F.E. Paige, T.L. Trueman and T.N. Tudron, Phys. Rev. D19, 935 (1979); J. Ranft and G. Ranft, Nucl. Phys. B165, 395 (1980).
[12] P. Chiappetta and G. Nardulli, Zeit. Phys. C51, 435 (1991).
[13] P. Chiappetta, P. Colangelo, J.P. Guillette and G. Nardulli, Zeit. Phys. C59, 629 (1993).
[14] C. Bourrely, and J. Soffer, Nucl. Phys. B445, 341 (1995).
[15] T. Gehrmann and W.J. Stirling, Zeit. f. Phys. C65, 461 (1995).
[16] M. Glück, E. Reya, W. Vogelsang, Phys. Lett. B359, 201 (1995).
[17] P. Chiappetta and M. Perrottet, Phys. Lett. B253 489 (1991)
[18] A. Fiandrino and P. Taxil, Phys.Rev. D44, 3490 (91) and Phys. Lett. B293, 242 (92).
[19] P. Taxil and J.M Virey, hep-ph 9604331, submitted to Phys. Lett. B
[20] G. Altarelli et al., CERN-TH/96-20 (January 1996) hep-ph 9601324.
[21] P. Chiappetta et al., PM/96-05, CPT-96/P.3004 (January 1996) hep-ph 9601306; P. Chiappetta in these proceedings.
$\Lambda = 1.6 \text{ Tev}$

$A_{LL}^{PV}$

$E_T$ (Gev)

Fig 2
\( \Lambda = 2.0 \text{ TeV} \)

\( \epsilon \eta = -1 \)

\( \epsilon \eta = 1 \)

\( A_{LL}^{PV} \)

\( E_T (\text{Gev}) \)

Fig 3
Fig 4