Could large CP-violation be detected in polarized proton collisions at RHIC?

V. L. Rykov [1]

Wayne State University, Detroit, MI 48201, USA

The measurable asymmetries which could be an indication of CP- and/or T-violation in charged current leptoproduction by polarized protons are discussed.

Summary

What is discussed?

- The single- and double-spin leptoproduction asymmetries and their relative sensitivities to CP-odd terms of the phenomenological charged current lagrangian.
- Crude estimates for spurious "T-odd-like" asymmetries due to initial and final state interactions and the possible ways to distinguish them from the true CP-violating effects.

What is not discussed?

- The nature of CP-violating phenomenological terms (Higgs, Leptoquarks, Supersymmetry, ...).
- The (model dependent) limits to CP-odd asymmetries at the energy scale of $W^{\pm}/Z^0$ mass, arising from low energy searches for CP- and T-violation.
- The dilution of asymmetries due to (strong/loose?) correlations of quarks' and antiquarks' polarizations to the polarizations of colliding protons.

Conclusion

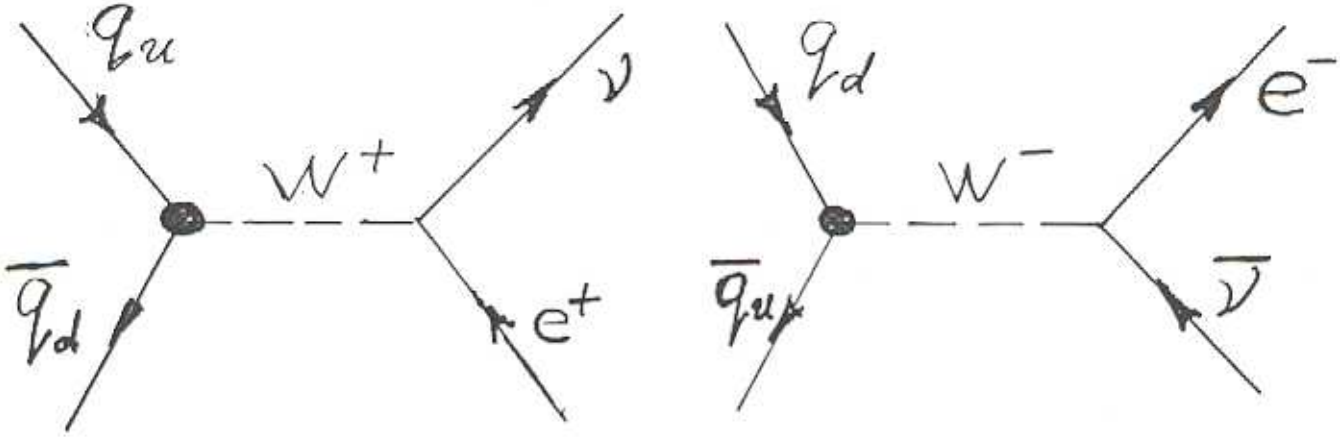
(i) The measurement of T-odd correlations on the order of at least $\sim 10^{-2}$ is possible in polarized proton collisions at RHIC.
(ii) The observation of nonzero T-odd correlations in $W^{\pm} \to e(\mu)\nu$ mode would be a strong indication of CP- and/or T-violation at about the weak coupling scale.

Issues to address in more details

(i) RHIC sensitivity to the broken CP- and/or T-symmetries in both quark and lepton coupling sectors, including also hadron decay modes of $W^{\pm}$ (and probably even Z^0 ?) bosons.
(ii) Separation of "true" T-odd correlation from the "spurious" asymmetries.
(iii) Systematic errors due to the experimental tolerances (spin alignment, etc)
(iv) Predictions of various models as well as the limitations to CP- and/or T-violating asymmetries at RHIC energies, arising from the earlier accomplished experiments.
(v) Search for other CP- and T-violating processes that might be potentially interesting for Spin Physics Program at RHIC.
(vi) ...(???)

[1] Phone: (313)–577–2781; fax: (313)–577–0711; e-mail: rykov@physics.wayne.edu

If free polarized quarks could be collided at RHIC



Disclamer: There is (almost?) no hope to measure at RHIC *CP*-violating asymmetries due to *CP*-odd phase in CKM-matrix.

<u>*T*-odd correlations in $q\bar{q}$ C.M. system:</u>

$$\boldsymbol{k}\cdot[\boldsymbol{\zeta}_q \times \boldsymbol{p}] \;; \qquad \boldsymbol{k}\cdot[\boldsymbol{\zeta}_q \times \boldsymbol{p}] \;; \qquad \boldsymbol{k}\cdot[\boldsymbol{\zeta}_q \times \boldsymbol{\zeta}_{\bar{q}}].$$

$\boldsymbol{p}$ is momentum of quark ($\boldsymbol{p} \equiv \boldsymbol{p}_q$);

$\boldsymbol{k}$ is momentum of lepton ($\boldsymbol{k} \equiv \boldsymbol{k}_\nu$ or $\boldsymbol{k} \equiv \boldsymbol{k}_{e^-}$);

$\boldsymbol{\zeta}_q$ is polarization of quark;

$\boldsymbol{\zeta}_{\bar{q}}$ is polarization of antiquark.

<u>**At least one quark has to be transversely polarized**</u>.

Phenomenological interaction lagrangian:

(*G. L. Kane, G. A. Ladinsky, and C. P. Yuan, Phys.Rev.* ***D45*** *(1992) 124*)

$$L = \frac{g}{\sqrt{2}}\{[W_\mu^- \overline{q}_d \gamma^\mu (f_1^L P_- + f_1^R P_+) q_u + \text{h.c.}] - \frac{1}{M_W}[\partial_\nu W_\mu^- \overline{q}_d \sigma^{\mu\nu} (f_2^L P_- + f_2^R P_+) q_u + \text{h.c.}] + \frac{1}{M_W}[\partial^\mu W_\mu^- \overline{q}_d (f_3^L P_- + f_3^R P_+) q_u + \text{h.c.}]\}$$

where $P_\pm = \frac{1}{2}(1 \pm \gamma_5)$, $i\sigma^{\mu\nu} = -\frac{1}{2}(\gamma^\mu\gamma^\nu - \gamma^\nu\gamma^\mu)$.

Using other notations,

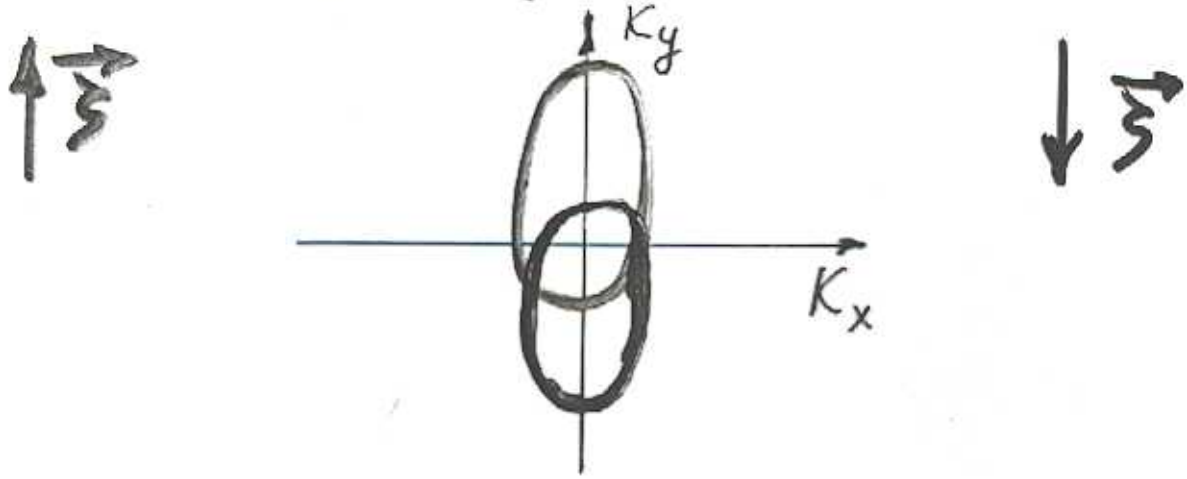
$$L = \frac{g'}{\sqrt{2}}\{[W_\mu^- \overline{q}_d \gamma^\mu (1 - \eta\gamma_5) q_u + \text{h.c.}] + \ldots\}$$

***CP*- and *T*-symmetries are broken if**

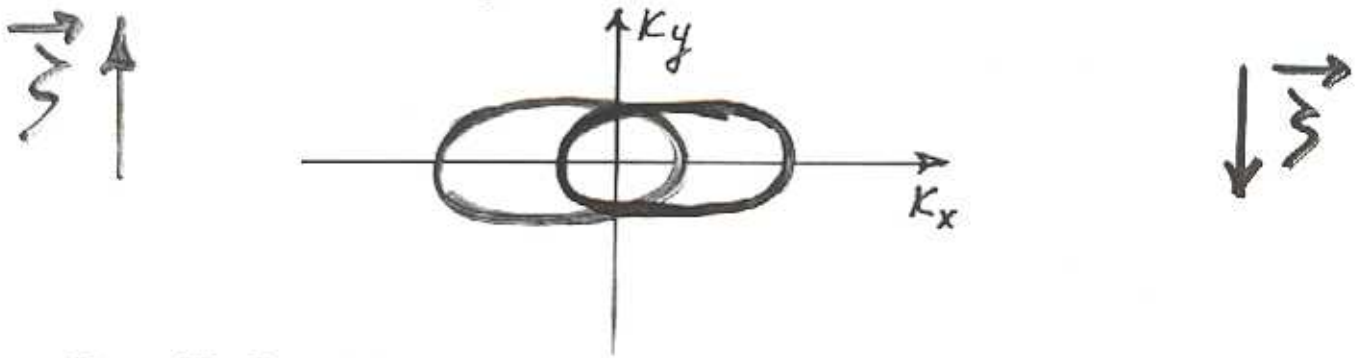
$$\text{Im}\{\eta\} \neq 0.$$

Single-spin asymmetries:

<u>T-even (but P-odd)</u>: $A \propto \frac{M_q}{S}(\boldsymbol{k} \cdot \boldsymbol{\zeta})$



<u>T-odd</u>: $A \propto \mathrm{Im}\{\eta\}\frac{M_q}{S^{3/2}}\boldsymbol{k} \cdot [\boldsymbol{\zeta} \times \boldsymbol{p}]$



Small double-spin asymmetries:

<u>**T-even**</u>: $A \propto \frac{M_q^2}{S^2}(\boldsymbol{\zeta}_q \cdot \boldsymbol{k})(\boldsymbol{\zeta}_{\overline{q}} \cdot \boldsymbol{k})$

<u>**T-odd**</u>:

<u>Both quarks transversely polarized</u>:

$$A \propto \mathrm{Im}\{\eta\}\frac{M_q^2}{S^{3/2}}\boldsymbol{k} \cdot [\boldsymbol{\zeta}_q \times \boldsymbol{\zeta}_{\overline{q}}]$$

<u>One quark longitudinally polarized</u>:

$$A \propto \mathrm{Im}\{\eta\}\frac{M_q}{S}\boldsymbol{k} \cdot [\boldsymbol{\zeta}_q \times \boldsymbol{\zeta}_{\overline{q}}]$$

$(1-|\eta|^2)(\vec{\xi}_1\cdot\vec{\xi}_2)$

(Potentially) Large double-spin asymmetries:

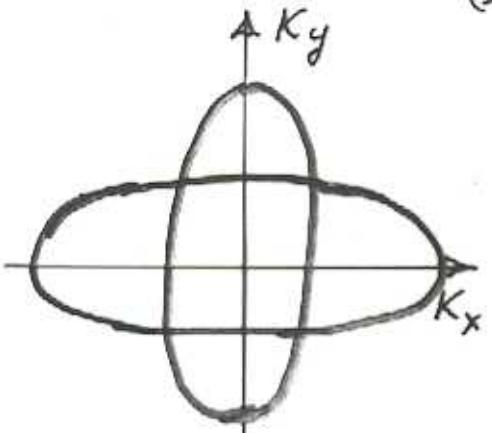
Parallel spins

Perpendicular spins

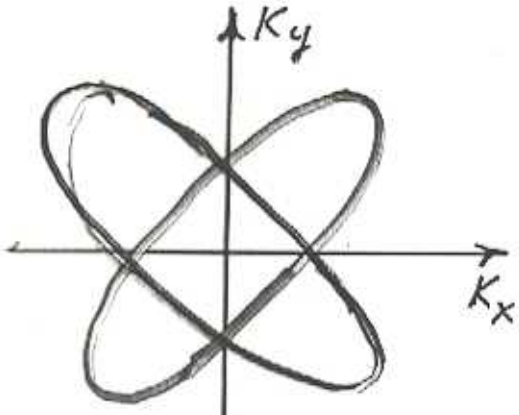
T-even:

$$A \propto (1-|\eta|^2)(\zeta_q\cdot k)(\zeta_{\bar{q}}\cdot k)/S$$

[redacted]



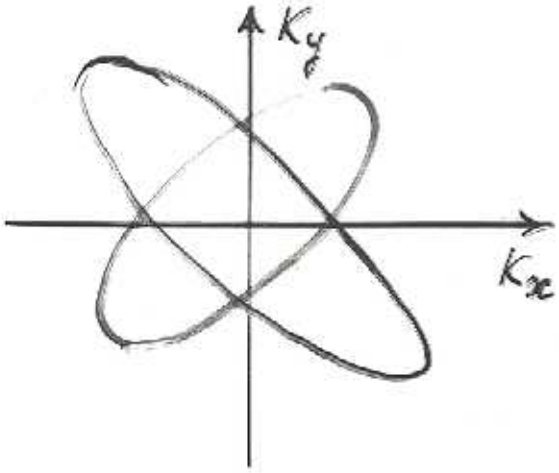
$\pm\cos 2\varphi$



$\pm\sin 2\varphi$

T-odd:

$$A \propto \pm\mathrm{Im}\{\eta\}\{\, k\cdot[\zeta_q\times p](\zeta_{\bar{q}}\cdot k) + k\cdot[\zeta_{\bar{q}}\times p](\zeta_q\cdot k)\}/S^{3/2}$$



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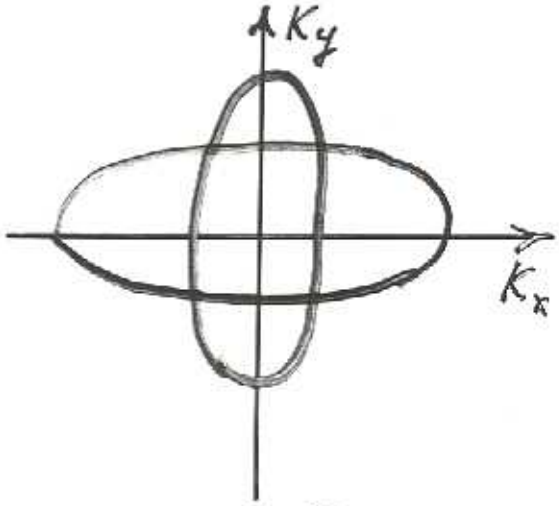
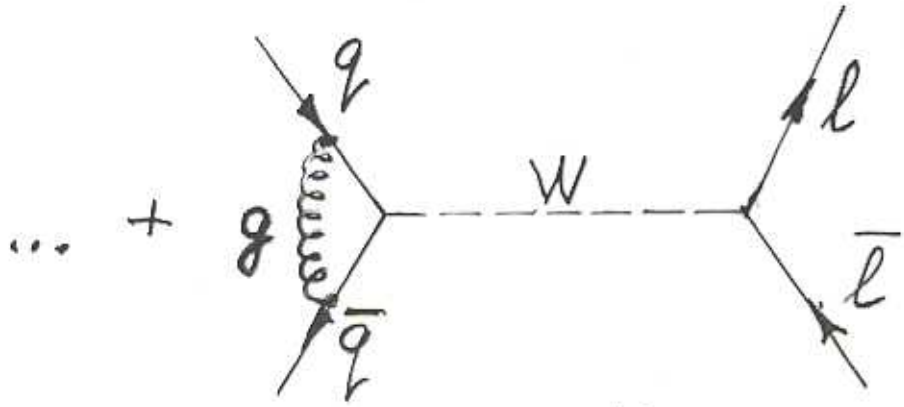


$\pm\cos 2\varphi$

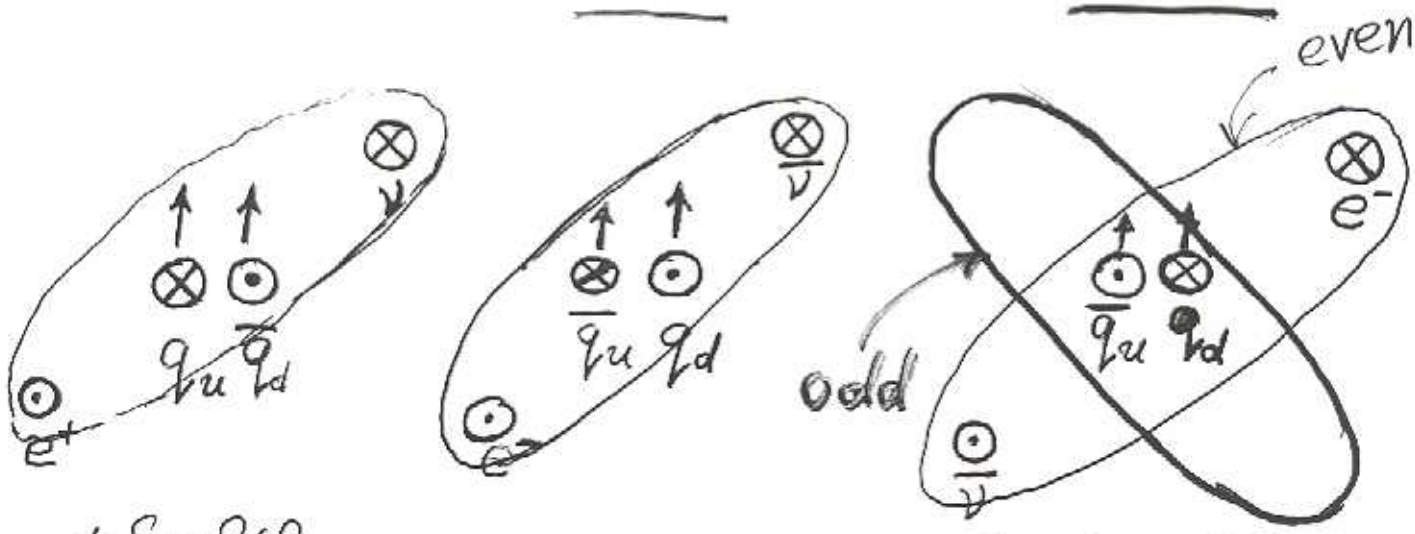
Spurious asymmetries



$$A_s \sim \alpha_s \frac{M_q}{\sqrt{s}} \lesssim 10^{-2} \text{ for } u,d,s,c,b$$

Is there any difference between "true" and "fake" asymmetry?

C CP



$+\sin 2\varphi$

$+\sin 2\varphi$ T-even

$-\sin 2\varphi$ T-odd