Polarizations in inclusive processes

M.G. Ryskin, Sov.J.Nucl.Phys. 48 (1988) 708

The model is simple
and contains the transparent physics.

Shortness –
not clear how to calculate the corrections

1. **Polarization in pert. QCD is small**

$$P \sim \alpha_s m_q / q_T$$

2. **Non-pert. model**

3. **Matching with pert.QCD**

4. **Hyperon polarization**

5. **Inclusive pion asymmetry**

Polarization need the shift of the phase between the 'spin-flip' and 'non-flip' amplitudes.

$$P \;\propto\; Im(M_{n.f.} M^*_{s.f.})$$

The quark-gluon vertex γ_μ conserves the helicity.
Quark mass in the propagator needed to flip the helicity.

Next to generate the imaginary part an extra gluon exchange is needed.
Thus in pert. QCD

$$P \sim \frac{\alpha_s}{\pi}\frac{m_q}{q_T} \;<\; 1\%$$

for $q_T = 2$ GeV, $\alpha_s = 0.3$ and $m_s = 150$ MeV
(we use the *current* quark mass in pert.QCD)

However $P_\Lambda \sim 0.3$ was observed experimentally !

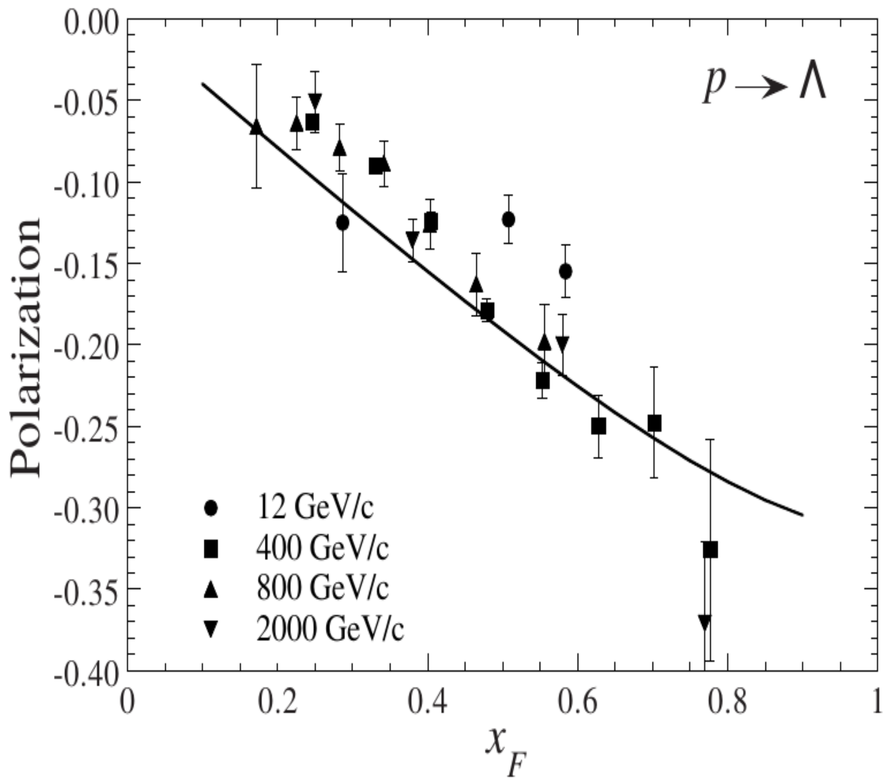


Figure 1. Λ polarization in the pp collision at $p_T = 1\mathrm{GeV}/c$ with the experimental data.

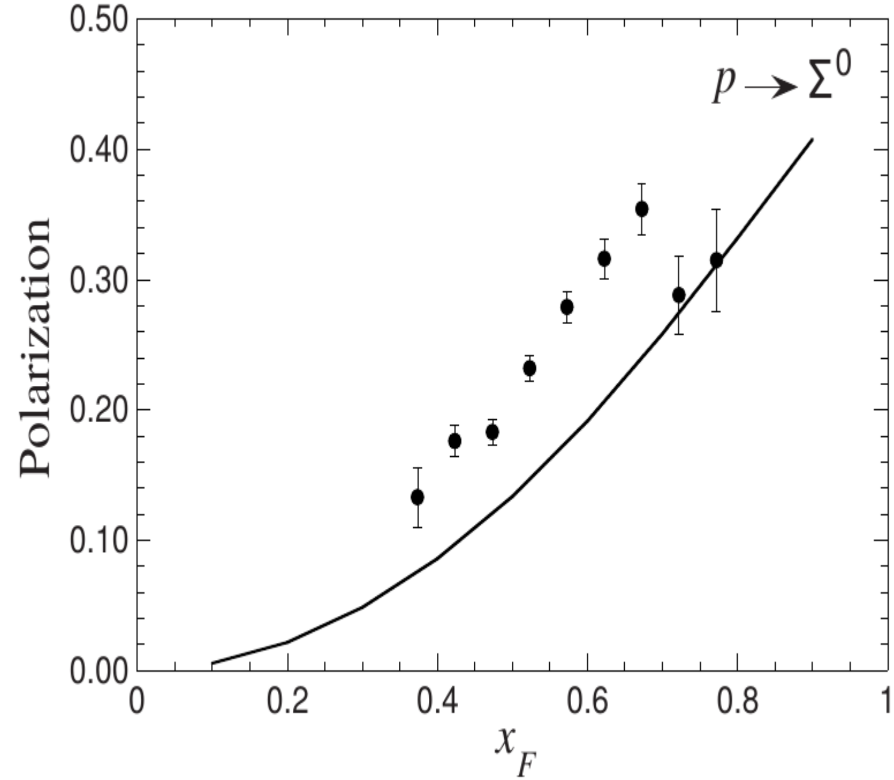


Figure 2. Σ polarization in the pp collision at $p_T = 1\mathrm{GeV}/c$ with the experimental data.

Non-Pert. model

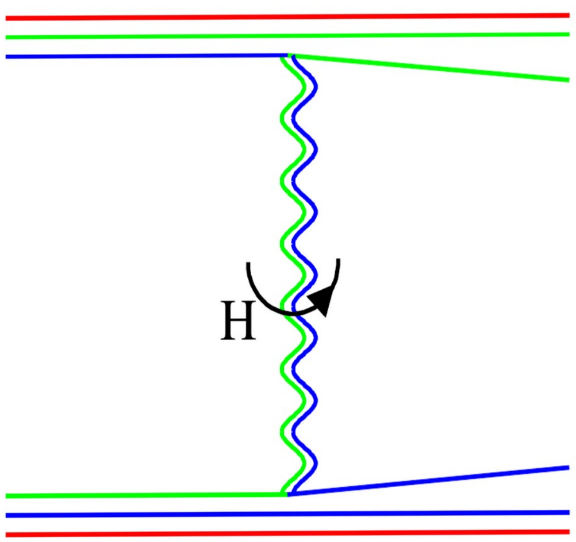
After the gluon exchange
the colour tube/string is created.
The string with the colour-electric field is unstable.
The colour-magnetic field is appeared,
like around the conductor with electric current in QED.

The strength of this colour-magnetic field is

$$H \simeq \frac{\sqrt{\alpha_s(R_c)}}{1.6 R_c^2}$$

("THE STRUCTURE OF A GLUON STRING"

A.B. Migdal S.B. Khokhlachev, JETP Lett. 41 (1985) 194.)



$R_c \sim 1/400 MeV \quad \alpha_s(R_c) \sim 0.5$

Here it is better to use the constituent quark mass.
$m_q = 330$ MeV and $m_s = 500$ MeV

The μH interaction leads to an *additional* quark transverse momentum

$$\delta q_T \simeq \mu H \simeq \frac{\alpha_s C_F}{2m_q 1.6 R_c^2} \approx 100\mathrm{M}eV$$

Asymmetry of a polarized quark production

$$A = \frac{d\sigma/d^3q_\uparrow - d\sigma/d^3q_\downarrow}{d\sigma/d^3q_\uparrow + d\sigma/d^3q_\downarrow} = \frac{d\sigma(q_T+\delta q_T) - d\sigma(q_T-\delta q_T)}{d\sigma(q_T+\delta q_T) + d\sigma(q_T-\delta q_T)} =$$

$$= \delta q_T \frac{\partial}{\partial q_T}\left(\frac{d\sigma}{d^3q}\right)\left(\frac{d\sigma}{d^3q}\right)^{-1},$$

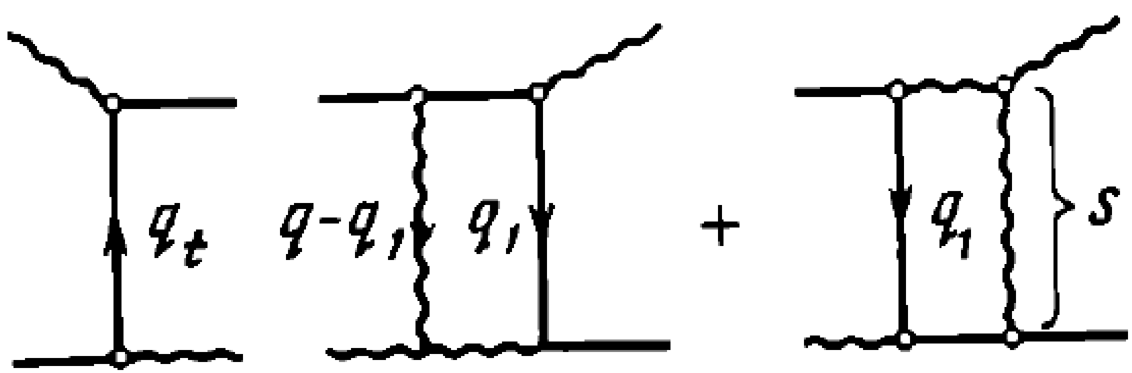
This can be compared with the pert.QCD result

The interference of Fig.1a and 1b diagrams gives

$$A = 0{,}95 \alpha_s q_T m / (q_T{}^2 + m^2)\,,$$

corresponding to $\delta q_T = \alpha_s m_q / 2 \simeq 80 \mathrm{M}eV$

since $$\frac{\partial}{\partial q_T} \left(\frac{d\sigma}{dq_T{}^2} \right) \left(\frac{d\sigma}{dq_T{}^2} \right)^{-1} = \frac{2q_T}{m^2 + q_T{}^2}.$$



a b

Single spin asymmetry for $p_\uparrow p \to \pi + X$ in pert.QCD.

M. Anselmino, M. Boglione, F. Murgia

Phys. Lett.B 362 (1995) 164

$$\frac{E_\pi \, d\sigma^{p^\uparrow p \to \pi X}}{d^3\boldsymbol{p}_\pi} \sim \frac{1}{2} \sum_{a,b,c,d} \sum_{\lambda_a,\lambda'_a;\lambda_b;\lambda_c,\lambda'_c;\lambda_d} \int d^2\boldsymbol{k}_{\perp a} dx_a \, dx_b \, \frac{1}{z}$$
$$\rho^{a/p^\uparrow}_{\lambda_a,\lambda'_a} \, \underline{\hat{f}_{a/p^\uparrow}(x_a, \boldsymbol{k}_{\perp a})} \, f_{b/p}(x_b) \, \hat{M}_{\lambda_c,\lambda_d;\lambda_a,\lambda_b} \, \hat{M}^*_{\lambda'_c,\lambda_d;\lambda'_a,\lambda_b} \, D^{\lambda_c,\lambda'_c}_{\pi/c}(z) \, ,$$

where $\hat{f}$ denotes the $\boldsymbol{k}_\perp$ dependent number density.

$$A_N \propto \quad \Delta^N f_{a/p^\uparrow}(x_a, \boldsymbol{k}_{\perp a}) \equiv \sum_{\lambda_a} \left[\hat{f}_{a,\lambda_a/p^\uparrow}(x_a, \boldsymbol{k}_{\perp a}) - \hat{f}_{a,\lambda_a/p^\downarrow}(x_a, \boldsymbol{k}_{\perp a}) \right]$$
$$= \sum_{\lambda_a} \left[\hat{f}_{a,\lambda_a/p^\uparrow}(x_a, \boldsymbol{k}_{\perp a}) - \hat{f}_{a,\lambda_a/p^\uparrow}(x_a, -\boldsymbol{k}_{\perp a}) \right]$$

Λ-hyperon polarization

$$\Lambda_\lambda \;=\; s_\lambda + (ud)_{scalar} \text{ that is } \quad P_\Lambda \;=\; P_{s-quark}$$

For $d\sigma/dq_T^2$ we use

$$x d\sigma/dx dq_T^2 \backsim \exp\left(-4xq_T - 1{,}9q_T^2 + 0{,}66q_T^3 - 0{,}07q_T^4\right)$$

Pondrom L. G. **Univ. of Wisconsin Thesis, 1984.**

$(p + Be \rightarrow \Lambda + X \quad 400 \text{ GeV}) \qquad q_T > 1GeV$

This gives $\quad P_\Lambda = -0{,}28x - 0{,}27q_T + 0{,}14q_T^2 - 0{,}02q_T^3.$

$|P_\Lambda|$ increases with x and q_T (up to $q_T \simeq 1.5$ GeV)

At small q_T the cross section $d\sigma/dq_T^2 \propto \exp(-Bq_T^2)$ leading to $P_\Lambda \propto q_T$.

Asymmetry in $p_\uparrow p \to p + X$ is small

For the Pomeron exchange (PPP and PPR terms) we have no colour string near the leading proton.

In the case of RRP and RRR terms the leading valence quarks pick up the new slow quark which mainly goes to the scalar diquark. That is the polarization is lost.

Inclusive $p_\uparrow p \to \pi + X$ pion asymmetry

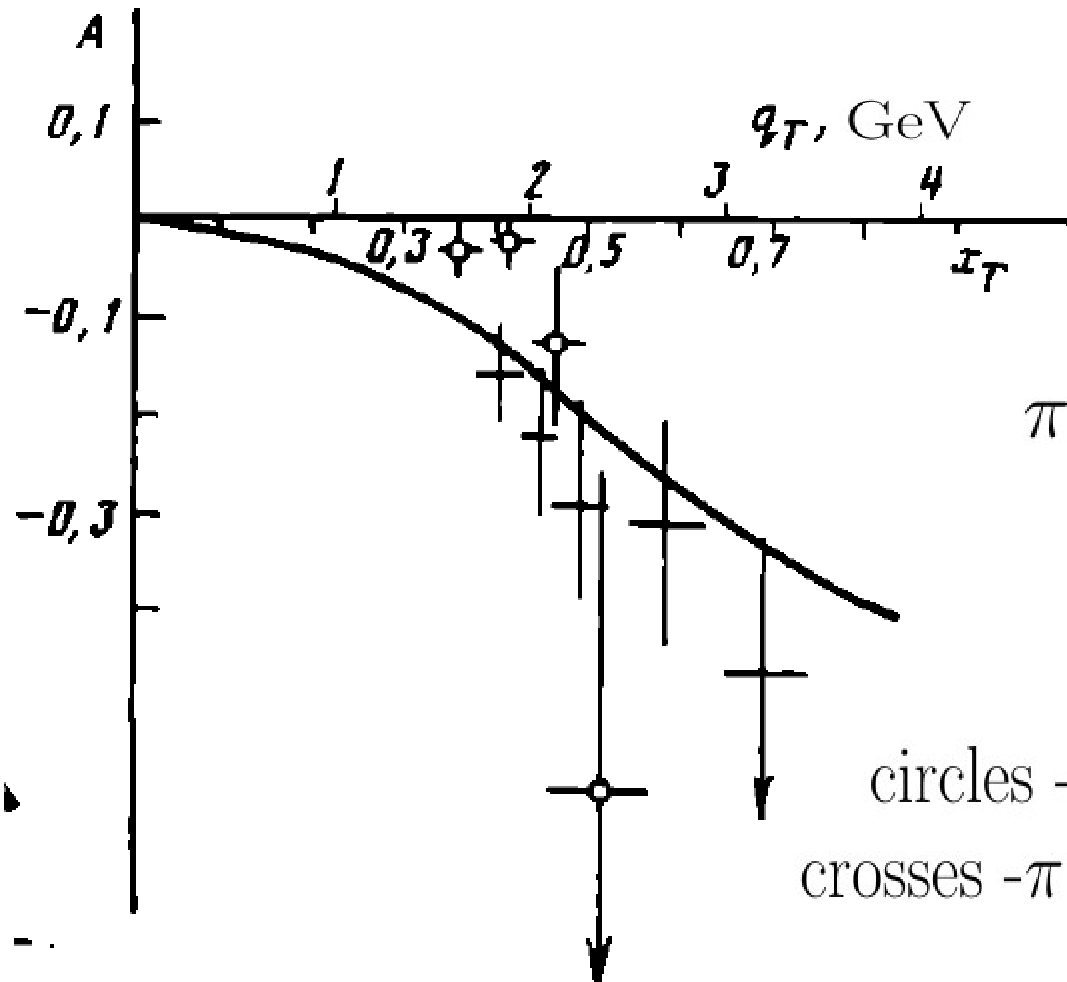
$$A_\pi = A_q P_q \sigma(q)/(\sigma(q)+\sigma(g))$$

A_q is the quark asymmetry
P_q is the quark polarization in $p_\uparrow$,

factor $\sigma(q)/(\sigma(q) + \sigma(g))$ is the fraction of the pions created by this (polarized) quark.

In first approx. $P_q \simeq x$

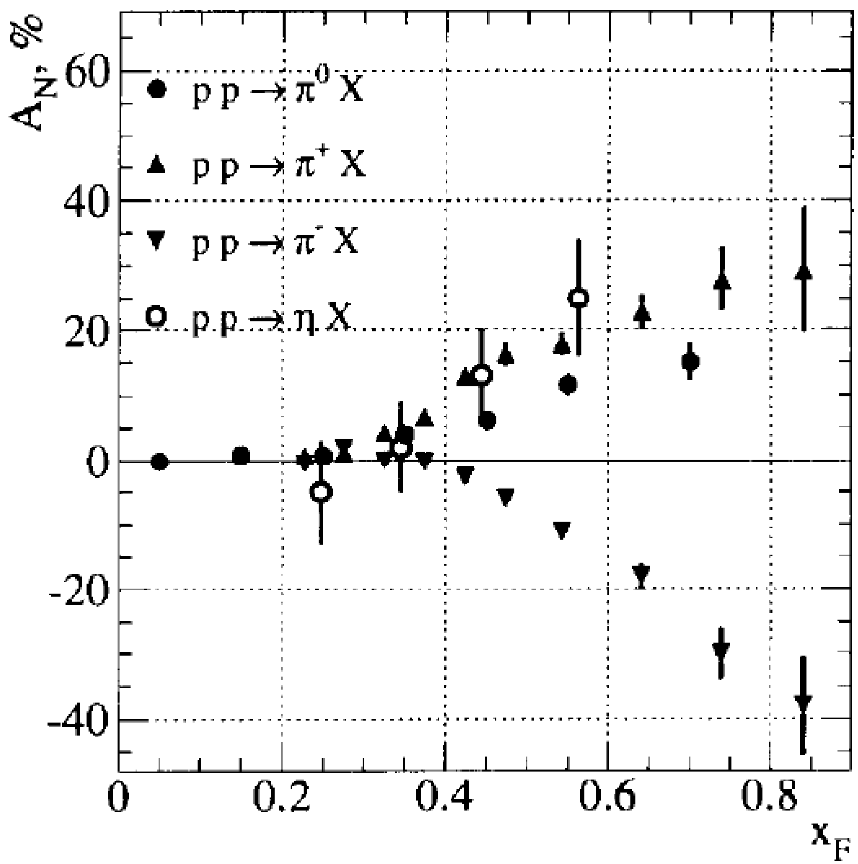
with $\delta q_T = 100$ MeV and $d\sigma/dq_T^2 \propto \exp(-4.5 q_T)$ we get



π at 90^o in c.m.s

circles - $pp_\uparrow \to \pi^0 + X$ at 24 GeV

crosses -$\pi^- p \to \pi^0 + X$ at 40 GeV



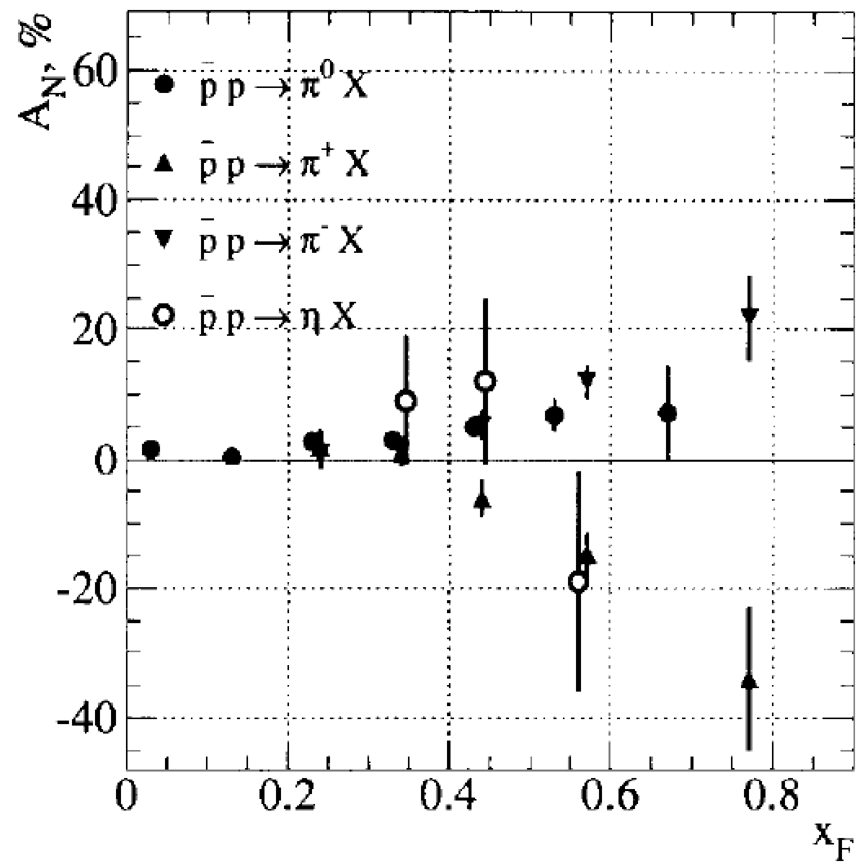


Fig. 4. (Left) The comparison plot of single spin asymmetries in the polarized proton beam fragmentation region.

Fig. 5. (Right) The comparison plot of single spin asymmetries in the polarized antiproton beam fragmentation region.

Conclusion

A simple model is suggested which enables one to

evaluate the polarization effects in inclusive reactions

making use of the q_T dependence of the x-section $Ed\sigma/d^3q$

Other non-pert. models

A SEMICLASSICAL MODEL FOR THE POLARIZATION

Bo ANDERSSON, G. GUSTAFSON, G. INGELMAN, Ph.Lett. 85B (1979) 417

tunelling $\bar{q}q$ pair production
local conservation of angular moment (L=-S) and k_T

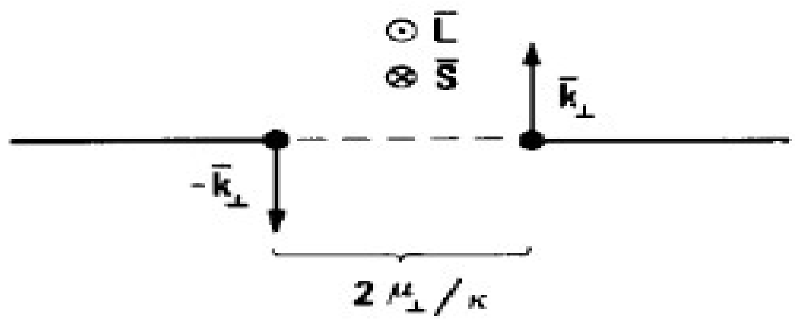


Fig. 5.20. A quark and an antiquark with transverse momenta $\bar{k}_\perp$ and $-\bar{k}_\perp$ are produced at a distance $2\mu_\perp/\kappa$ from each other. They carry an orbital angular momentum $\bar{L}$ which is compensated if the spins are polarized in the opposite direction.

$$L \propto \mu_\perp \; = \; \sqrt{k_T^2 + m_q^2}$$

Models for polarization asymmetry in inclusive hadron produc.

T.A. DeGrand, H.I. Miettinen, Ph. Rev. D24 (1981) 2419

Quark spin is rotated due to Thomas precession when the *see* quark is accelerated.

$$P \propto v \propto 1/m_q$$

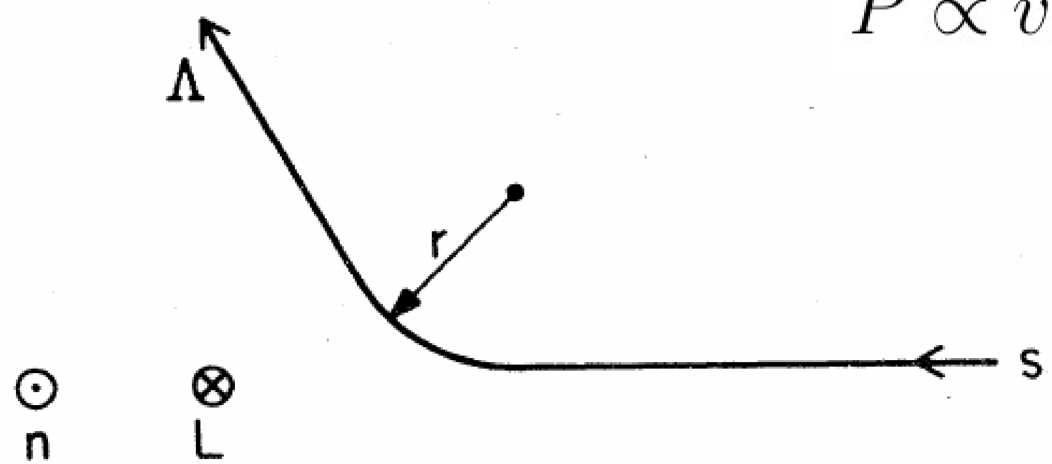


FIG. 3. Semiclassical trajectory of a particle in an attractive potential showing the distance of the orbit from the origin $\vec{r}$, and the orientations of the scattering plane

A New Mechanism for Single Spin Asymmetries in Strong Interactions

JETP Lett. 72 (2000) 481

N.I. Kochelev

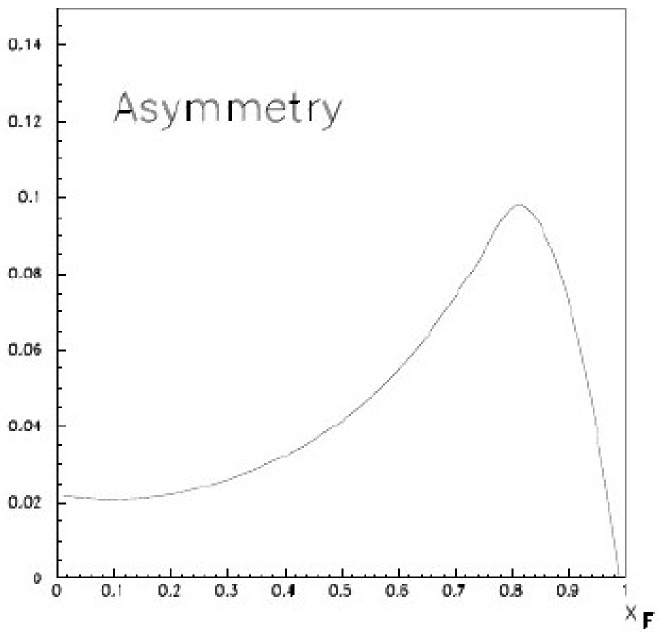


Figure 2: *The instanton contribution to the single spin asymmetry for pion production as a function of x_F.*

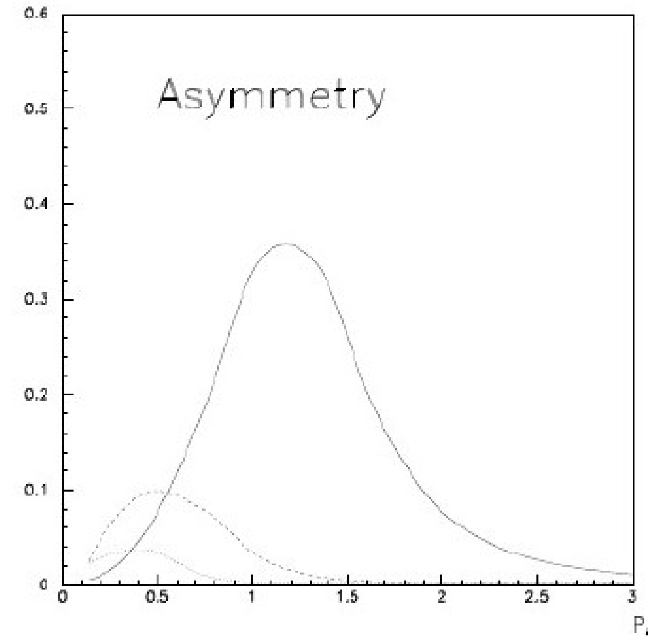
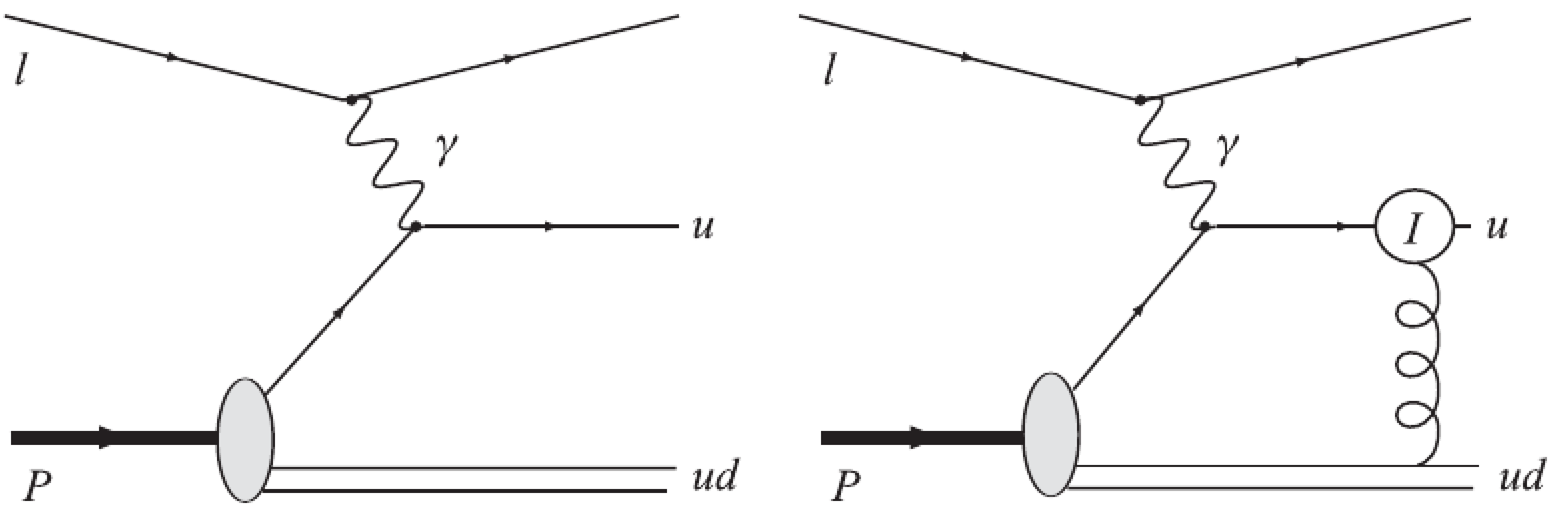


Figure 3: *The instanton contribution to the single spin asymmetry for pion production as a function of x_F and $p_t = |l_\perp|$. Solid line is for $x_F = 0.9$, dashed line is for $x_F = 0.6$ and dotted line is for $x_F = 0.3$.*

SINGLE SPIN ASYMMETRIES IN HIGH ENERGY REACTIONS AND NON-PERT. QCD EFFECTS

A. E. Dorokhov, N. I. Kochelev, W.-D. Nowak

Phys.Part.Nucl.Lett. 6 (2009) 440-445 • e-Print: 0902.3165



The diagrams giving rise to SSA in SIDIS. The symbol I denotes the instanton

QCD Instanton flips the quark spin !

Instanton is the classical solution of QCD equations.

A.A.Belavin, A.M.Polyakov, A.S.Schwatz and Yu.S.Tyupkin,

Phys.Lett.**59B**, 85 (1975)

$$A^a_\mu(x) = \frac{2}{g}\eta_{a\mu\nu}\frac{(x-x_0)_\nu}{(x-x_0)^2+\rho^2}$$

$\alpha_s = g^2/4\pi$, ρ= instanton radius,

$\eta_{a\mu\nu} = 0$ for $\mu = \nu = 4$

$\eta_{a\mu\nu} = -\delta_{a\nu}$ for $\mu = 4$

$\eta_{a\mu\nu} = \delta_{a\nu}$ for $\nu = 4$

$\eta_{a\mu\nu} = \epsilon_{a\mu\nu}$ for $\mu, \nu = 1, 2, 3$

At $x \to \infty$ instanton is the pure gauge field

$$g\frac{\tau^a}{2}A_\mu^a \to iS\partial_\mu S^+$$

with $S = i\tau_\mu^+ x_\mu/\sqrt{x^2}$

However for $x \neq \infty$ it is the real transverse gluon field which describes the transition between two different (in gauge) QCD vacuums.

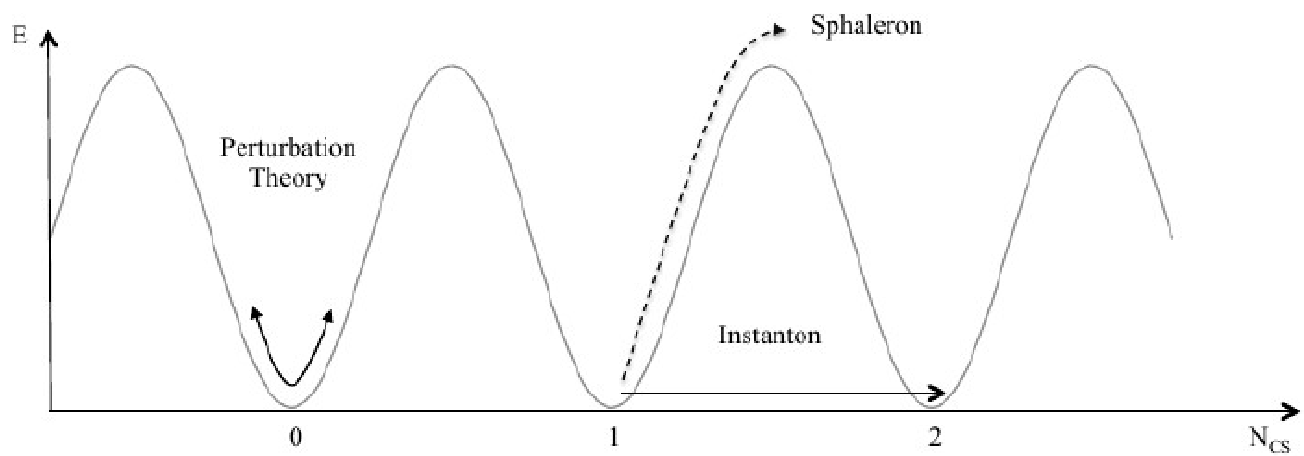


Figure 1. Instanton and Sphaleron processes in the topology of a Yang-Mills vacuum; energy density of the gauge field (y-axis) vs. winding number N_{CS} (x-axis).

The statistical weight of size-ρ instanton is

$$D(\rho, \mu_R) = \frac{\kappa}{\rho^5} \left(\frac{2\pi}{\alpha_s(\mu_R)} \right)^6 (\rho\mu_R)^{b_0}$$

where $(\rho\mu_R)^{b_0} = \exp(-2S^I)$ $\qquad S^I = 2\pi/\alpha_s$

$$\kappa = 0.0025 \exp(0.292 N_f) \sim 0.01$$

Instanton induced spin-spin corr^n.

$$q_{Li} + q_{Lk} ==> I ==> n_g \cdot g + \sum_f (q_{Rf} + \vec{q}'_{Lf});\ i \neq k,\ \textbf{for}\ \vec{q}'\ f \neq i,\ f \neq k$$

$$q_R + q_R ==> \bar{I} ==> n \cdot g + \sum_f (q_{Lf} + \vec{q}'_{Rf}) \qquad n \sim 1/\alpha_s(\rho)$$

Instanton rearrange the Dirac basement
One extra level of light left quark appears while the level of right quark goes upstairs to continuum spectra.

In electro-week case where the γ_5 anomaly is canceled between the quarks and the leptons this leads to the *baryon charge non-conservation.*

In QCD this is the helicity non-conservation.

The idea is to exploit the Instanton induced spin-spin correlations. Indeed in terms of Feynman diagrams the instanton/sphaleron looks as the non-local vertex with n_g gluon and $2n_f$ fermion legs; n_f is the number of light quarks with $m_q < \rho$ (m_q is the curent quark mass, ρ is the instanton size).
That is 2 (quark + antiquark) legs for each light flavour. Instanton absorbs left quark and emits right quarks (absorbs right antiquarks and emits left antiquarks)

$$q_{Li} + q_{Lk} ==> I ==> n_g \cdot g + \sum_f (q_{Rf} + \bar{q}'_{Lf}); \; i \neq k, \; \textbf{for } \bar{q}' \; f \neq i, \; f \neq k$$

$$q_R + q_R ==> \bar{I} ==> n \cdot g + \sum_f (q_{Lf} + \bar{q}'_{Rf}) \qquad n \sim 1/\alpha_s(\rho)$$

Strong instanton gluon field rearranges the Dirac basement. One extra level of light left quark appears while the level of right quark goes upstairs to continuum spectra.
This is connected with the γ_5 anomaly.

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In electro-week case where the γ_5 anomaly is canceled between the quarks and the leptons this leads to the *baryon charge non-conservation.*

In QCD this is the helicity non-conservation.

This can be checked experimentally by studying the spin-spin correlations, say in

$$p_\uparrow \; + \; p \; \rightarrow \; \Sigma \; + \; X$$

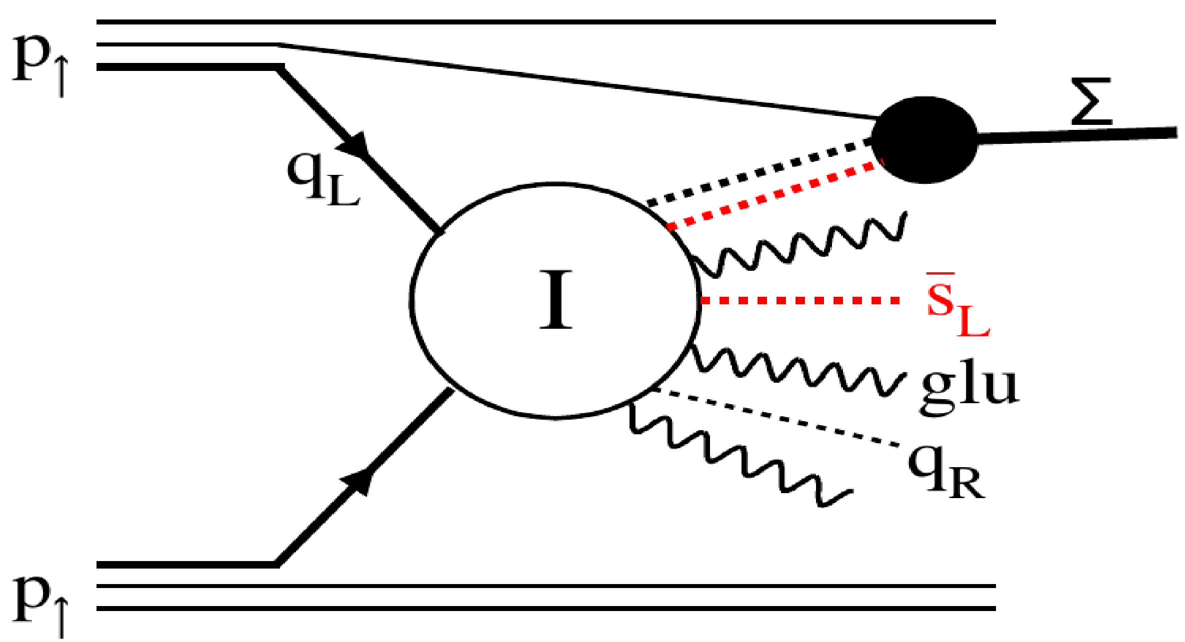
First at the quark level the instanton *doubles* the incoming polarization. Instead of one left u_L-quark it produces two right quarks - u_R and s_R. To distinguish the 'left' and 'right' quarks we need the weak interaction, that is the weak decay of Σ or Λ hyperons. (Another possibility is to produce the $\bar{\Lambda}\Lambda$ pair and to check that Λ is *right* while $\bar{\Lambda}$ is *left*.)

To confirm that it was the instanton/sphaleron we may observe a larger than usual (at this energy) multiplicity and a stronger energy ($\sqrt{s}$) dependence and/or the spin-spin correlation when the second beam is polarized (instanton absorbs two *left* quarks only).

In QCD instanton vacuum models the typical instanton size $\rho \sim 0.3 fm = 1/600$ MeV and the separation between the instantons is $R \sim 1 fm$.
The cross section to create the $\rho = 0.3 fm$ sphaleron is about

$$\rho^2 \cdot (\rho/R)^2 \times \text{ Ringvald factor} \sim 1 mb$$

(see e.g. Tab.2 of 1911.09726)
However the probability to form the hyperon from these quarks is small. So I would expect $\sigma \sim 1$ μb.



The problem is that we have No trigger. The possibilities are:
a) to have the trigger on high multiplicity
b) to select (if possible) the events with V-vertex due to hyperon(strange) decay.

THANK YOU

In QCD this is the helicity non-conservation.

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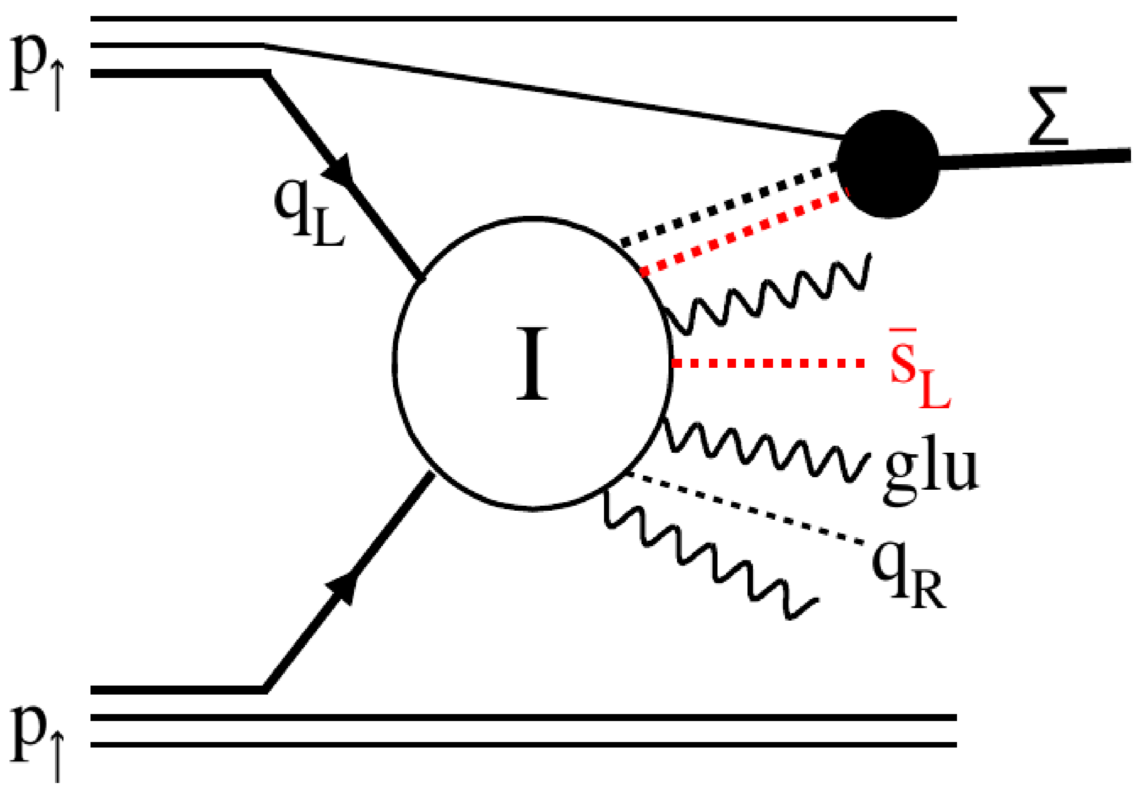
$$p_{\uparrow} + p \rightarrow \Sigma^0 + X$$



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THANK YOU