Diffractive π^0 production, chiral symmetry & the odderon

(C. Ewerz & O. Nachtmann, 2006)

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1 Introduction

The odderon was introduced more than 30 years ago (Lukaszuk, Nicolescu, 1973; Joynson et al. 1975).

odderon: $C = P = -1$ exchange object in high energy scattering.

So far there is only weak experimental evidence for an odderon from $pp / p\bar{p}$ elastic scattering at $\sqrt{s} = 53$ GeV, $|t| \cong 1.3$ GeV^2.

There are by now many suggestions to look for the odderon in other reactions.

We are concerned here with

diffractive π^0 photo & electroprod.

$$\gamma^{(*)}(q) + p(p) \longrightarrow \pi^0(q') + p(p'),$$

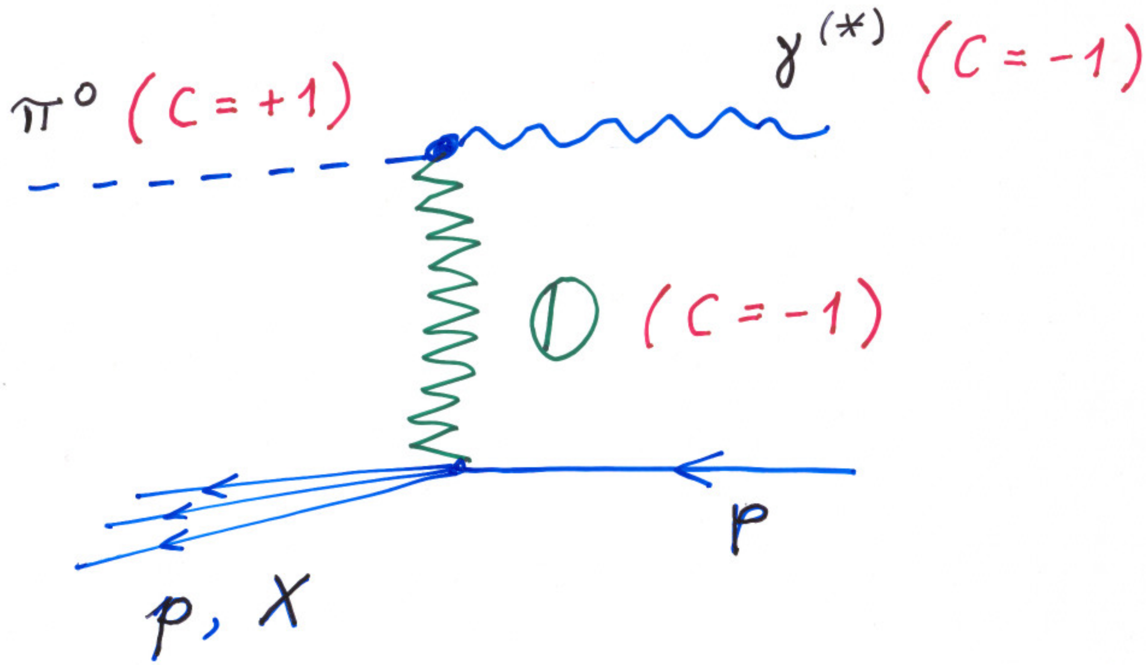
$$\gamma^{*}(q) + p(p) \longrightarrow \pi^0(q') + X(p').$$

(X e.g. N^*)

Schäfer, Mankiewicz, O.N.,	1991
Barakhovsky et al.	1991
Kilian & O.N.	1998
* Berger et al.	1999
Berger et al.	2000
Donnachie, Dosch, O.N.	2006

Our original cross section estimate turned out to be too large compared to experiment:

$$\sigma(\gamma p \to \pi^0 N^*) \begin{cases} \approx 300\ \text{nb} & \text{theory } * \\ < 49\ \text{nb} & \text{H1 exp.} \end{cases}$$



(read all diagrams from right to left!)

2 Chiral symmetry

Quark fields and axial currents

$$\psi(x) = \begin{pmatrix} u(x) \\ d(x) \end{pmatrix}$$

$$A^a_\mu(x) = \bar{\psi}(x)\gamma_\mu\gamma_5 \frac{\tau_a}{2}\psi(x)$$

$$a = 1, 2, 3$$

PCAC relation

$$\partial_\lambda A^{a\lambda}(x) = \frac{f_\pi m_\pi^2}{\sqrt{2}}\phi^a(x)$$

$f_\pi \cong 130$ MeV, pion decay constant

$\phi^a(x)$ is a correctly normalised pion field operator.

PCAC relates π^0 and axial current production

$$\gamma^{(*)}(q,\nu) + p(p) \longrightarrow \pi^0(q') + p(p')$$

$$\mathcal{M}^{\nu}(\pi^0; q', p, q)$$

$$\gamma^{*}(q,\nu) + p(p) \longrightarrow A^3(q',\mu) + p(p')$$

$$\mathcal{M}^{\mu\nu}(A^3; q', p, q)$$

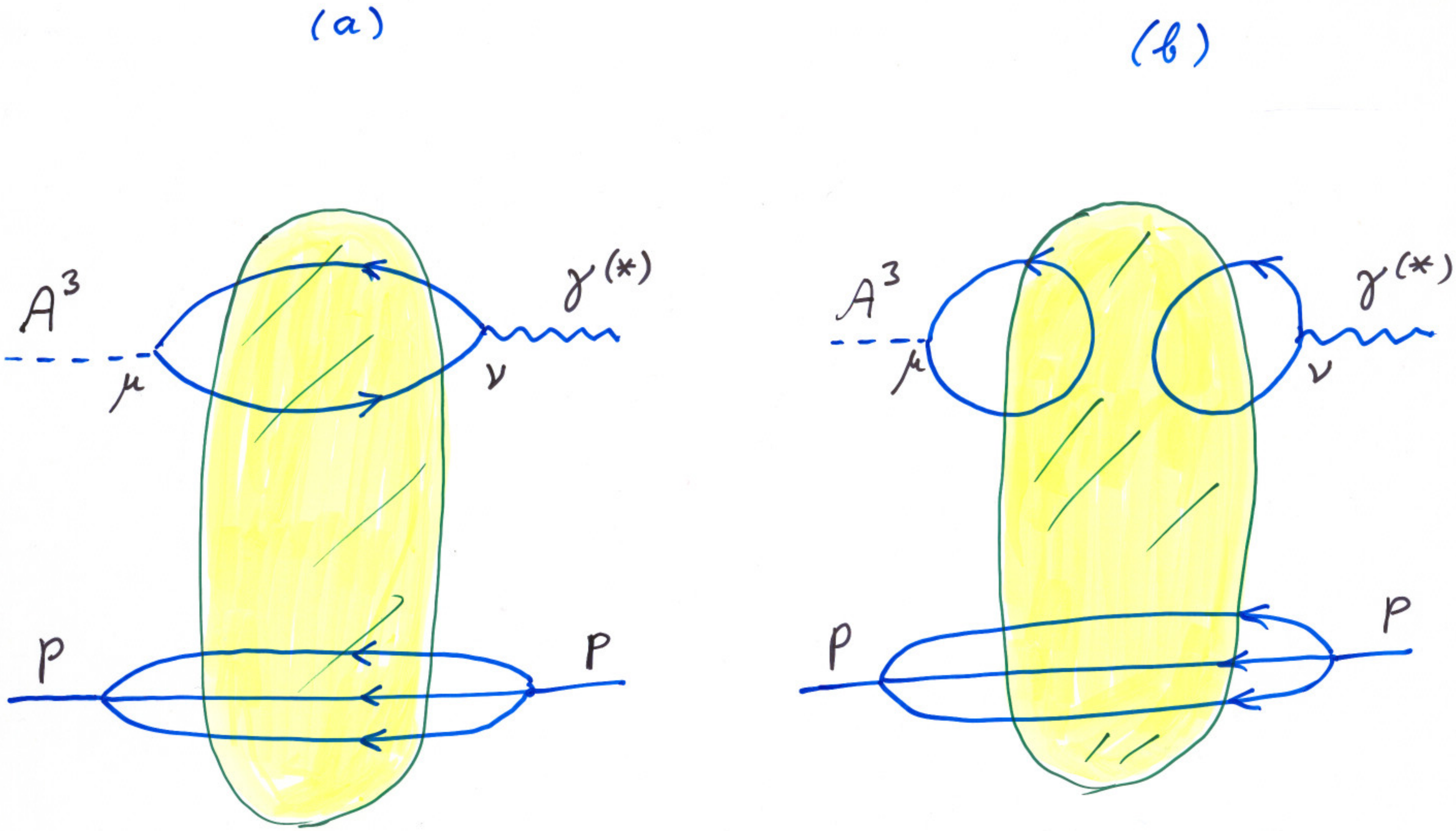
$$q^2 = -Q^2 \leq 0 \quad , \quad q'^2 \leq m_\pi^2$$

$$\boxed{\mathcal{M}^{\nu}(\pi^0; q', p, q) = \frac{2\pi\, m_p \sqrt{2}}{f_\pi\, m_\pi^2} \left(-q'^2 + m_\pi^2\right) i q'_\mu\, \mathcal{M}^{\mu\nu}(A^3; q', p, q)}$$

3 Axial current production

The analysis is similar to the one of Compton scattering (C. Ewerz & O.N. 2006)

- use LSZ formula to relate the amplitude to Green's functions
- represent Green's functions as functional integrals over quark and gluon degrees of freedom
- integrate out the quark degrees of freedom $\Longrightarrow$ quark skeleton diagrams
- select the quark skeleton diagrams which are expected to be leading at high energies, that is, the odderon exchange diagrams



Odderon exchange diagrams for $\gamma^{(*)} p \rightarrow A^3 p$

$\longrightarrow$ quark prop. in given gluon pot.;  integration over all gluon pot.

4 From axial current to pion production

Take the divergence in diagrams (a) and (b):
multiplication with q'^{μ}, resp. derivative ∂^{μ}
At quark level:

$$\partial^{\mu} A^{3}_{\mu} = i \{ m_u \bar{u} \gamma_5 u - m_d \bar{d} \gamma_5 d \}$$

This gives one factor m_q in the divergenc amplitude.
By explicit inspection one finds that the loops in (a) and (b) give a further factor m_q.

- The divergence amplitude is proportional to $(m_q)^2$

$(q = u, d)$

From the theory of chiral symmetry we know:

$$m_\pi^2 = 2B \, \frac{1}{2} (m_u + m_d)$$

$$B = -\frac{2}{f_\pi^2} \langle 0 | \bar{u}(x) \, u(x) | 0 \rangle \cong 1800 \, \mathrm{MeV}$$

$\Longrightarrow$

$$\mathrm{Ampl}(\gamma^* p \to \pi^0 p) \underset{\mathrm{PCAC}}{\propto} \frac{1}{m_\pi^2} \mathrm{Ampl}(\gamma^* p \to \partial^\mu A_\mu^3 \, p)$$

$$\propto \frac{1}{m_\pi^2} m_q^2 \propto m_\pi^2$$

- In the chiral limit, $m_\pi^2 \to 0$, the amplitude for π^0 production via odderon exchange vanishes

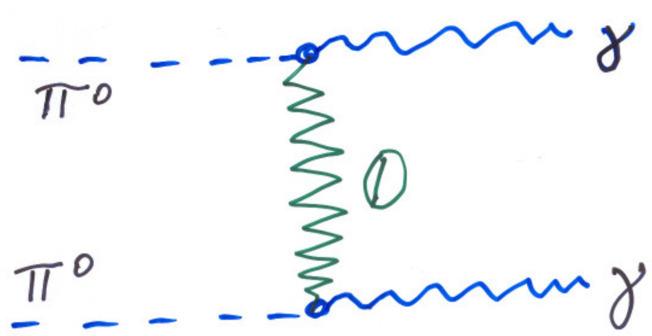
5 Conclusions

- Chiral symmetry leads to a suppression of odderon exchange diagrams for $\gamma^{(*)} p \longrightarrow \pi^0 X_{diffr.}$
- Numerical estimate (Donnachie, Dosch, O.N. 2006):

$$\sigma(\gamma p \longrightarrow \pi^0 N^*) \approx 6\ nb \text{ or less}$$

- A large suppression is predicted for

$$\gamma \gamma \longrightarrow \pi^0 \pi^0$$



End result, everything properly renormalised:

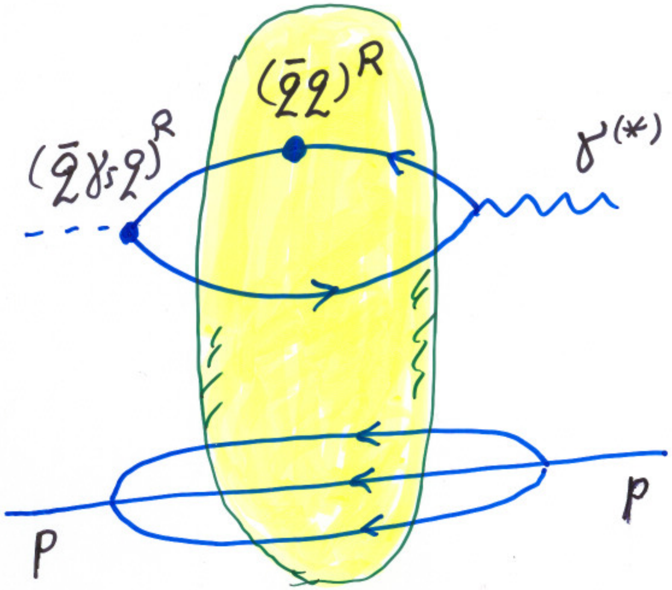
$$\mathcal{M}^{\nu}(\pi^0; q', p, q) = m_\pi^2 \frac{\pi\, m_p}{f_\pi B^2 \sqrt{2}} \; i\,(q'^2 - m_\pi^2)$$

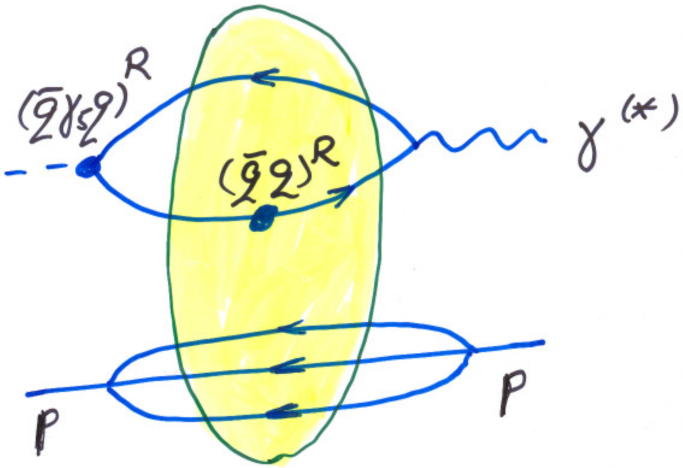
$$\left\{ - r_u^2 \; C^{(u)\nu}(q', p, q) + r_d^2 \; C^{(d)\nu}(q', p, q) \right\}$$

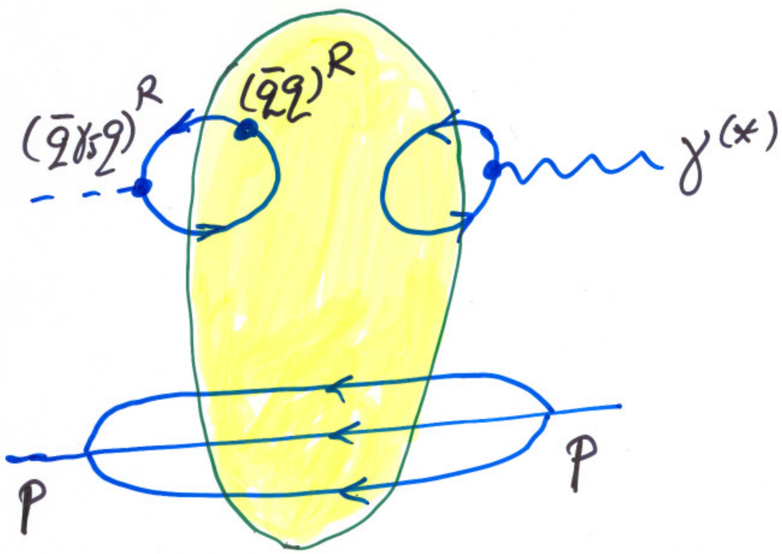
$$r_u = \frac{2 m_u}{m_u + m_d} \cong 0.6 \quad , \quad r_d = \frac{2 m_d}{m_u + m_d} \cong 1.4$$

$$(2\pi)^4 \delta^{(4)}(p' + q' - p - q)\; C^{(q)\nu}(q', p, q) = -\frac{1}{2\pi m_p} \int d^4x \, d^4x' \, d^4z$$

$$e^{iq'x'} e^{-iqx} \langle p(p') | T^* \left(\bar{q}(x')\gamma_5 q(x')\right)^R \left(\bar{q}(z) q(z)\right)^R J^{\nu}_{em}(x) \,|\, p(p) \rangle$$







Diagrams for the correlation function

$$C^{(q)\nu}(q', p, q)$$

$$(q = u, d)$$