STUDY OF CHARGE ASYMMETRY AT HERA, THERA, ...

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Main topics

1. *Possible discovery of odderon.*

2. *Breaking of quark – hadron duality.*

3. *Weighted cross sections. New structure functions.*

Charge asymmetry

of reaction products arises usually due to interference of different production mechanisms giving final states with opposite C–parity.

The well-known example is forward–backward asymmetry of muons, produced in the e^+e^- collisions at Z resonance. (Photon exchange (vector current) produces C-odd system and axial current in Z exchange produces C–even system.

In the quantities like total cross section charge asymmetry effects disappear. Dedicated study of charge asymmetry permit separate different mechanisms and study of new phenomena.

Possible discovery of odderon

• The Pomeron is Regge–pole type object having vacuum quantum numbers. It describes, in particular, elastic and total cross sections at high energies. It can be treated as some "particle" in t–channel with s–dependent "propagator" ($s^{\alpha_{\mathcal{P}}(t)}$):

$$M_{\mathcal{P}}(AB \to A'B') = e^{i\frac{\pi\alpha_{\mathcal{P}}}{2}} g_{AA'}(t) s^{\alpha_{\mathcal{P}}(t)} g_{BB'}(t)\,.$$

Here $\bar{\alpha}_{\mathcal{P}} = \alpha_{\mathcal{P}}(0)$ is the intercept of Pomeron and I include some remnant from standard signature factor to the vertexes g_a. According to modern data and QCD calculations in LLA (BFKL) $\bar{\alpha}_{\mathcal{P}} > 1$. In the QCD treatment Pomeron is based on two–gluon exchange in t–channel.

• Odderon is introduced as the object very similar to Pomeron. It is responsible, for instance, for the difference of pp and $p\bar{p}$ total cross sections. It has vacuum quantum numbers except C and P. Its C–parity is negative and P–parity is unnatural, like for the photon. Its contribution into the scattering amplitude is similar to that of Pomeron but with other signature factor and other intercept:

$$M_O(AB \to A'B') = ie^{i\frac{\pi\bar{\alpha}_{\mathcal{O}}}{2}}\bar{g}_{AA'}(t)s^{\alpha_{\mathcal{O}}(t)}\bar{g}_{BB'}(t)\,.$$

In the QCD motivated description of high energy phenomena odderon appears necessary. In the QCD treatment odderon is based on three–gluon exchange in t–channel. Since the gluon spin is 1, odderon's intercept is close to one. Unfortunately, we have no reliable calculations of this intercept even in LLA. Obtained results vary with time of preparation of paper ($\bar{\alpha}_O =$ $0.94 \to 0.96 \to 1 \to ?$).

The negative results in hunting of odderon are interpret as being due its weak coupling with proton and other hadrons. Since odderon contribution cannot be seen in the difference of pp and $\bar{p}p$ cross sections at present accuracy, we should find for other opportunities.

• Odderon at HERA/ THERA

The odderon left elusive object till now. HERA (in future THERA and Photon Colliders) provides best opportunities for its discovery since a series of reactions exist governed by odderon exchange at high energy — diffractive type processes with rapidity gap between produced meson M and proton remnant X:

$$\gamma p \to M + X, \quad (M_X^2 \ll s)$$

with $M = \pi^0,\ \eta,\ f_0,\ f_2,\ a_2^0$, etc.

I.F. Ginzburg, D.Yu. Ivanov,
Nucl. Phys. **B 388** (1992) 376

Recently cross sections of these processes at small transverse momenta were calculated with some "plausible" assumptions (in particular, upper values of parameters permissible by modern limitations):

E.R. Berger, A. Donnachie, H.G. Dosch, O. Nachtmann et al., Phys. Rev. **D 59** (1999) 014018; Eur. Phys. J. **C9** (1999) 491; hep-ph/0001270

The calculated cross sections are low. Besides, the uncertainty introduced by hypotheses about value of couplings is high.

Using of charge asymmetry

Recently S.J. Brodsky, J. Rathsman, C. Merino, Phys. Lett. **B461** (1999) 114 proposed to observe charge asymmetry in the photo-production of $c\bar{c}$ pair, due to interference between production of C–odd system (Pomeron exchange) and C–even system (odderon exchange). However, even the Pomeron mediated $c\bar{c}$ production cross section is small. The efficiency of c–quark recording is not high. Last, the obtained interference term contains small factor

$$Re\left[ie^{i\dfrac{\pi(\bar{\alpha}_{\mathcal{P}}-\bar{\alpha}_{\mathcal{O}})}{2}}\right] \propto \sin\left[\frac{\pi}{2}(\bar{\alpha}_{\mathcal{P}}-\bar{\alpha}_{\mathcal{O}})\right].$$

All these make the discovery of odderon in this reaction unprobable.

Recently we proposed to look for similar charge asymmetry due to interference between Pomeron and odderon in the diffractive photo-production of $\pi^+\pi^-$ pairs in events with rapidity gap at HERA.

I discuss this opportunity in more detail since this subject is interesting by itself and also we use it as a guide for future studies.

In I.F. Ginzburg, I.P. Ivanov, N.N. Nikolaev (in prep.) we consider diffractive type process

$$\gamma(p_1)p(p_2) \to \pi^+(p_+)\pi^-(p_-)X$$

with X =proton or some excitations of proton with not too high effective mass and $M = \sqrt{p_+ = p_-)^2} \sim 1$ GeV.

At large s the C-odd system of pions is produced via Pomeron exchange. The C-even system of pions is produced via odderon exchange. Each contribution itself give no charge asymmetry in cross section. Their interference results in charge asymmetry in the momentum distribution of pions.

We define:

$$q^\mu = p_+^\mu + p_-^\mu\,, \qquad \Delta^\mu = p_+^\mu - p_-^\mu.$$

Charge asymmetry is antisymmetry in distribution of Δ^μ (its components). We choose

- $$\xi = \frac{\varepsilon_+ + p_{+z} - \varepsilon_- - p_z}{E_+ + p_{+z} + \varepsilon_- + p_{-z}} \equiv \frac{\Delta \cdot p_2}{q \cdot p_2},$$
- $$v = \frac{\mathbf{p}_{+\perp}^2 - \mathbf{p}_{-\perp}^2}{M^2} \equiv \frac{(q_\perp \cdot \Delta_\perp)}{M^2}.$$

To describe charge asymmetry in the integral form, we propose to use **weighted cross sections** (some Fourier transforms in C–parity)

$$\sigma^{C\xi} = \int \xi \, d\sigma \, , \quad \sigma^{Cv} = \int v \, d\sigma \, .$$

Here we assume integration over all variables or some subset, for example, with fixing of M^2, or M^2 and $\mathbf{q}_\perp^2$, etc.
In these quantities C-even contributions disappear and only charge asymmetry term is left.

The production of dipions is assumed to be saturated by contributions of resonances having relatively large dipion decay modes:
• $\rho(770)$, $\rho(1450)$ $(J = 1)$, $\rho_3(1690)$ $(J = 3)$ for Pomeron exchange,
• $f_0(400 - 1200)$, $f_0(980)$, $f_0(1370)$ $(J = 0)$ and $f_2(1270)$ $(J = 2)$ for odderon exchange.

Now the amplitude of process can be written as a sum of contributions of resonances R decaying for $\pi^+\pi^-$:

$$\mathcal{M} = e^{i\frac{\pi\bar{\alpha}_{\mathcal{P}}}{2}} f_R(s,t) \frac{i\sqrt{Br(R\to\pi^+\pi^-)M\Gamma_R}}{\sqrt{\pi}(M^2 - m_R^2 - iM\Gamma_R)} \cdot \mathcal{E}_R$$

for Pomeron contributions. Here $d\sigma = |f(s,t)|^2 d\Gamma$. The odderon contributions has similar form with evident change of intercept and additional factor i in front. Factor $\mathcal{E}_R$ presents polarization dependence determined via moments of pions and proton. For the initial photon with polarization vector e^μ (helicity state $\sigma = +1$) we have for different helicity states λ of produced resonances

$$\mathcal{E}_R = \begin{cases} \frac{(eq)}{M}\xi^J & \text{for} \quad \lambda = 0\,, \\ \frac{(e\Delta)}{M}\xi^{J-1} & \text{for} \quad \lambda = 1\,, J \geq 1\,, \\ \frac{(e\Delta)(q_\perp\Delta_\perp)}{M^3}\xi^{J-2} & \text{for} \quad \lambda = 2\,, J \geq 2\,. \end{cases}$$

With these amplitudes the interference (charge asymmetry) is calculated easily via cross sections of discusses resonances production σ_R, their diffractive slopes b_R.

For example, assuming helicity conservation for ρ meson, the relative value of (ρ, f_0) interference as compare standard cross section of diffractive ρ-meson production is

$$R_{interf/diff} = v \cot 2 b_{f_0} M^2 \sqrt{\frac{\sigma_O(f_0)}{\sigma_{\mathcal{P}}(\rho)} \cdot \frac{6}{b_\rho M_\rho^2}} \cdot I(f_0, \rho)\,.$$

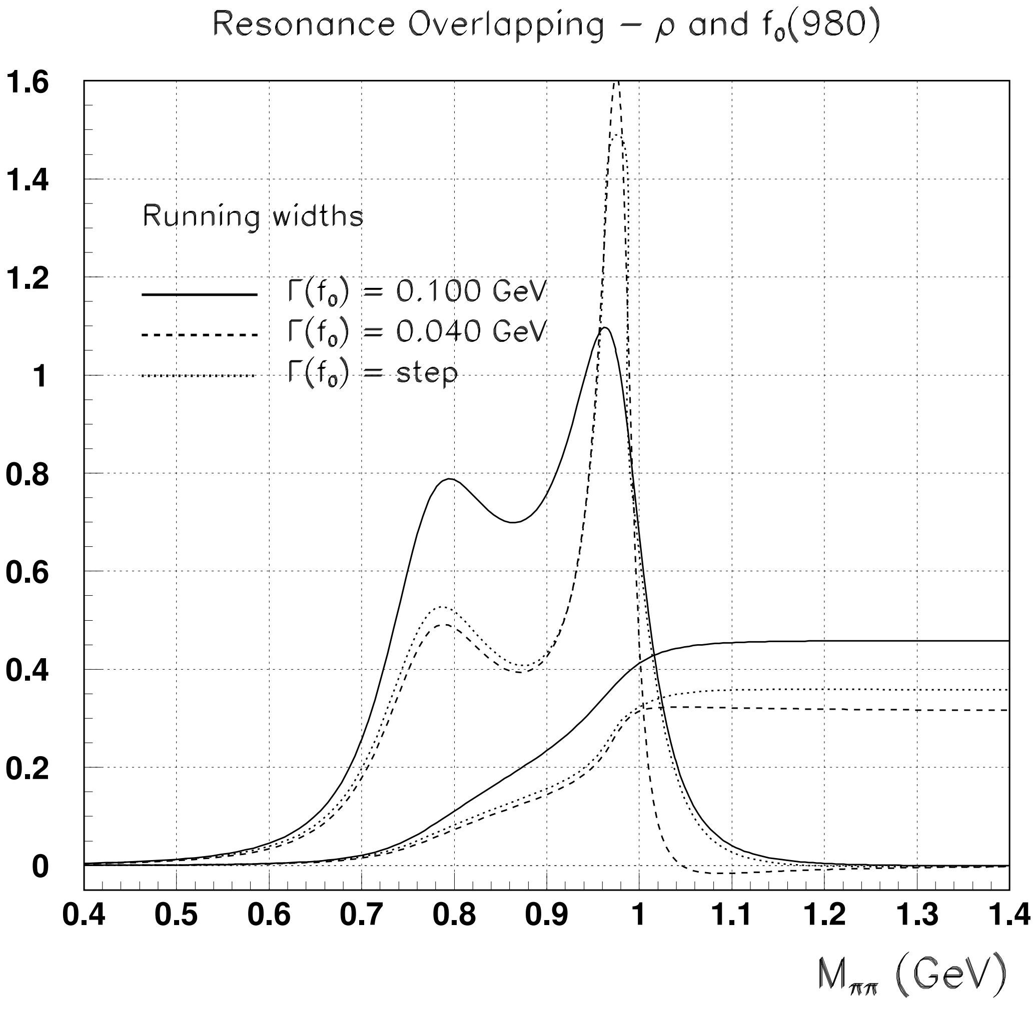
Similar interference for helicity flip amplitude for ρ meson is $\propto \xi$.

In the (f_2, ρ) interference contribution of helicity conserving amplitude for f_2 meson production $\lambda = 1$ is

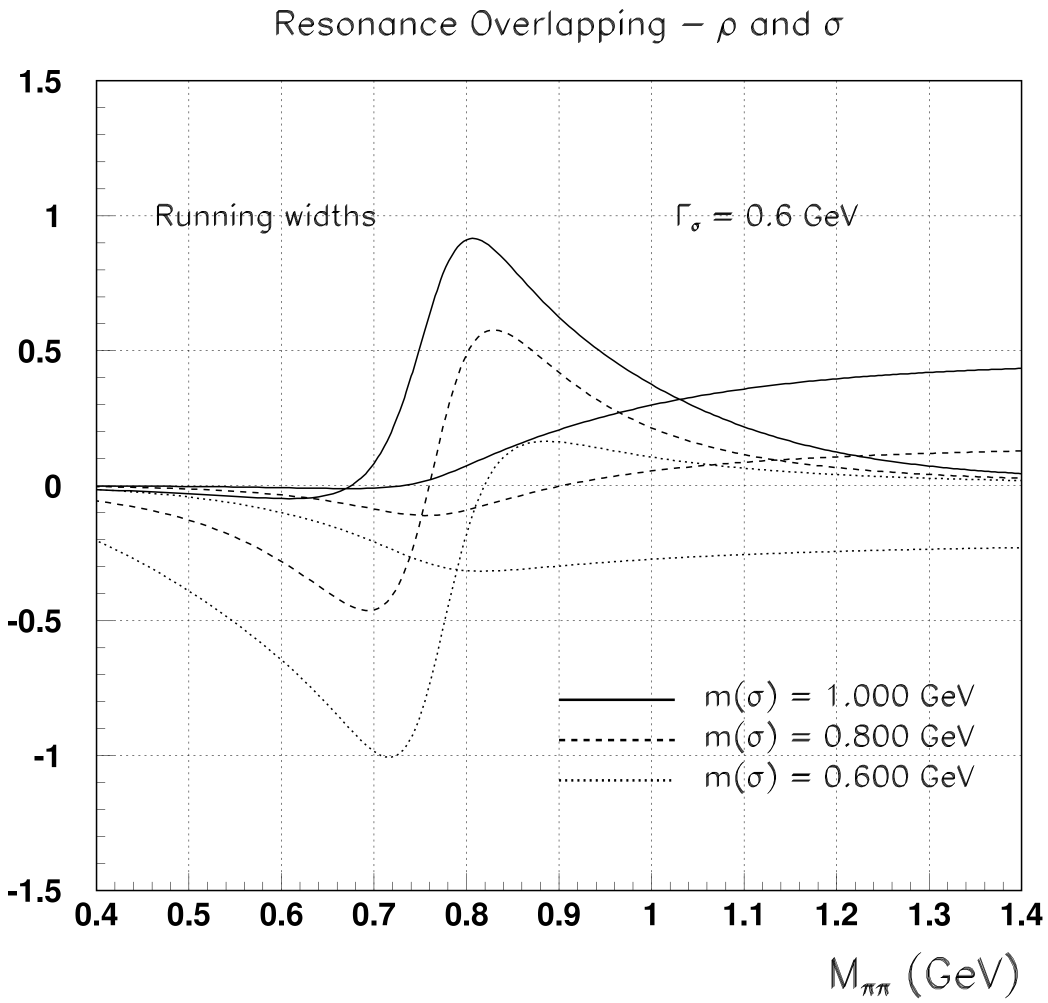
$$\propto \xi \cdot \frac{\Delta_\perp^2}{M^2} I(f_2, \rho), \ldots$$

Here $Br_i = Br(R_i \to \pi^+\pi^-)$ and the overlapping factor $I(R_1, R_2)$ equals

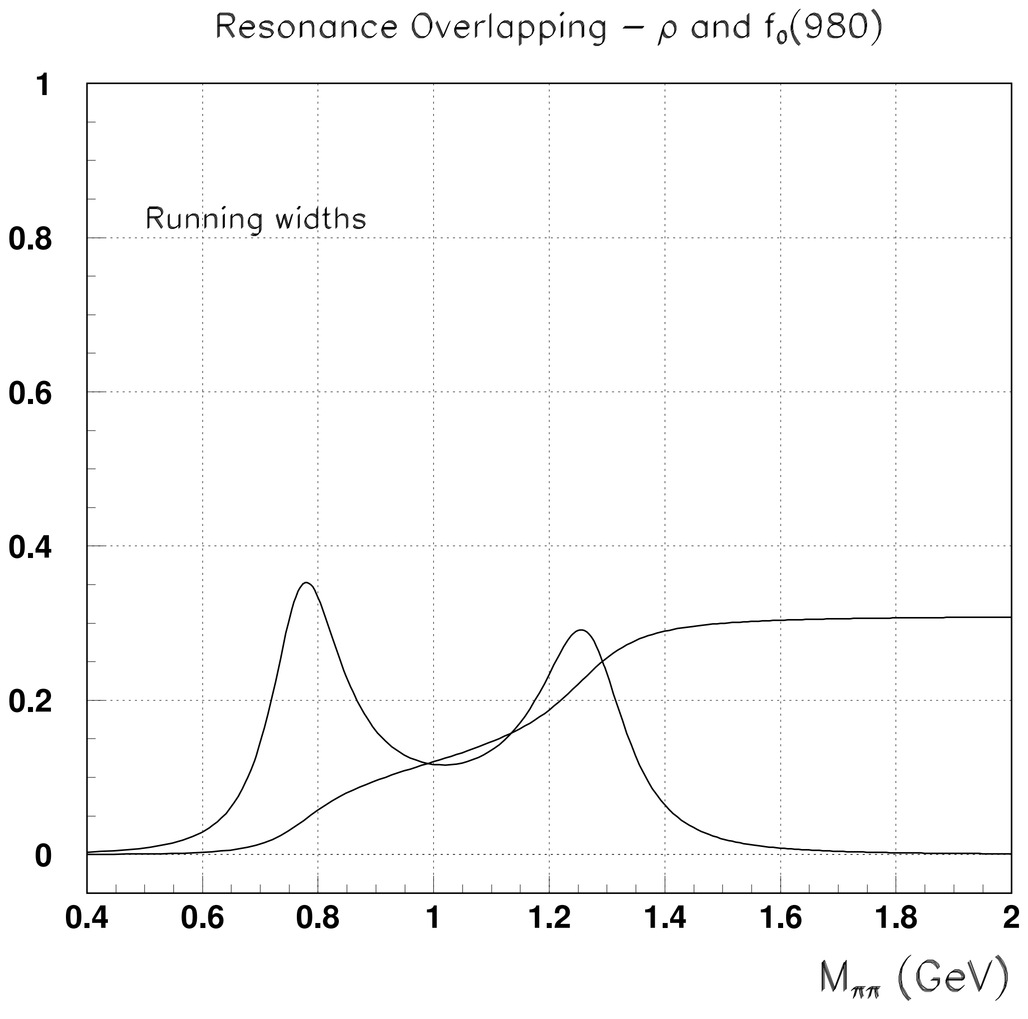
$$= Im \left(\frac{e^{i\frac{\pi(\bar{\alpha}_{\mathcal{P}} - \bar{\alpha}_{\mathcal{O}})}{2}} M \sqrt{\Gamma_1 \Gamma_2 Br_1 Br_2}}{\pi(M^2 - M_1^2 + iM\Gamma_1)(M^2 - M_2^2 - iM\Gamma_2)} \right)\,.$$



Overlapping function $I(f_0(980),\rho)$and integral from it over M^2 for different values of f_0 width. Difference in intercepts is neglected.



Overlapping function $I(f_0(400-1200),\rho)$*and integral from it over* M^2 *for different values of* f_0 *width. Difference in intercepts is neglected.*



Overlapping function $I(f_2, \rho)$*and integral from it over* M^2. *Difference in intercepts is neglected.*

For numerical estimates we assume slope parameter to be close to that for ρ–meson and use for the value of cross section estimate obtained in cited paper ($\sigma(\gamma p \to f_2 + X) \approx 30$ nb). The inaccuracy in this value is reduced in the interference item.
The obtained quantities for interference is few percents. It is large enough to see effect in the data.

The curves presented show that the contributions are concentrated near positions of resonances. Since relative signs of different contributions are unknown, some definite predictions can be given for for the regions near C–even resonances. The value of effect near the ρ meson cannot be predicted definitely.

Certainly, in the more detail description interference with Primakoff effect and ρ, ω trajectories for production of C–even resonances should be taken into account. The Primakoff effect contribution is concentrated at vey low total transverse momenta of produced pion pair. It can be eliminated by small cut in $q_\perp$.

The effect of other resonances needs for more detail estimates. It can be eliminated completely via measuring of energy dependence on effect. Moreover, it is calculable with good precision from low energy data. Assuming $g(f\rho\rho) \approx g(f\pi\pi)$ one can see that odderon contributions are dominate if $\sigma_O(f) > 0.1$ nb, that is much lower than estimate obtained in the cited paper.

Breaking of quark–hadron duality

The crucial feature of result is strong enhancement of interference term due to final state interaction (formation of resonances). The same is valid for the photo-production of c–quarks. Main source of observed D–mesons is decay of excited states of J/Ψ. That are $J = 1$ states of $c\bar{c}$ system, produced via Pomeron exchange. In the same region $J = 0$ and, perhaps $J = 2$ states of this $c\bar{c}$ system should be produced via odderon exchange. All these resonances are not very narrow. The overlapping of these resonances should give essential contribution to the charge asymmetry as it was discussed for pions. This interference has no small factor $\sin\left(\frac{\pi(\alpha_{\mathcal{P}} - \alpha_{\mathcal{O}})}{2}\right)$ obtained for the production of c–quarks itself by Brodsky et al.. Therefore,

charge asymmetry make clear breaking of quark–hadron duality due to final state interaction even for heavy quarks.

New structure functions?

Proposal for future studies

The introduced weighted cross sections gives an idea about new type of structure functions – weighted structure functions. They are determined for the set of events with total recorded charge of hadron system equal 0 (proton or some its excitation avoid observation – goes into the "tube"). That are structure functions based on cross sections with left or right–hand electrons weighted with charge asymmetry factors, similar to introduced above, for example,

$$\xi = \frac{\sum(p_2 \cdot p_{i+}) - \sum(p_2 \cdot p_{j-})}{\sum(p_2 \cdot p_{i+}) + \sum(p_2 \cdot p_{j-})},$$

The weighted cross sections and structure functions are determined as those given with weight ξ or V for each event:

$$d\sigma \to \xi d\sigma, \quad \text{and } v d\sigma\,.$$

These quantities can give new life for study of W_3 type function which responsible for the interference of γ and Z exchange.

It is easy to obtain that

$$\sigma^L - \sigma^R \propto Re(J_V^* J_A)\,,$$

where J_V is contribution of vector current (roughly determined by only photon exchange) and J_A is contribution of axial current (from Z exchange only). According to our experience in Higgs physics at $Q^2 > 1000$ GeV^2 these contributions become be close each other.

The gluon exchange effects don't seen in standard W_3 function. Indeed, vector current is C–odd source and axial Z current is C–even. Therefore, even with Pomeron exchange they produce diffractively states with opposite C-parity (ρ from vector current and f from axial current. This opportunity for Pomeron was not studied till now. The discussed interference disappear in total cross section and left in the weighted cross section where standard contributions disappear.

THERA (and Photon Colliders) has an exceptional potential in study of odderon and weighted structure functions due to higher electron energy and more wide range of Q^2 achievable for study.

Similar studies look very difficult for Tevatron, LHC and e^+e^- Linear Colliders.