# Hard exclusive wide-angle processes

P. Kroll

Fachbereich Physik, Universität Wuppertal

Cracow, June 2012

**Outline:**

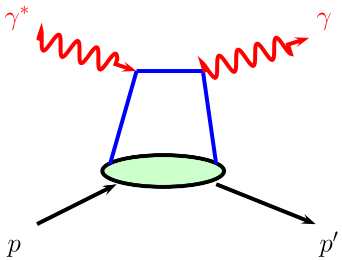
- **Factorization schemes**
- **Handbag factorization for** $\gamma\gamma \to M\overline{M}$
- **Flavor symmetry**
- **Results**
- **ERBL factorization for** $\gamma\gamma \to M\overline{M}$
- **Other exclusive wide-angle reactions**
- **Summary**

talk based on Diehl-Vogt-K hep-ph/0112274, Diehl-K 0911.3317

# Handbag factorization in excl. reactions

wide angles: large $s, -t, -u$ deeply virtual: large $Q^2$

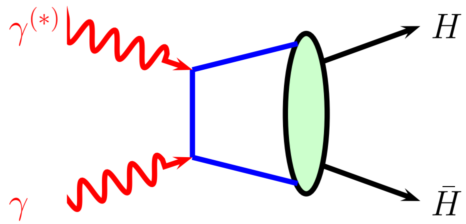
only one active parton (others are spectators, collinear fact.)




GPD

$\gamma^{(*)} p \to \gamma p$

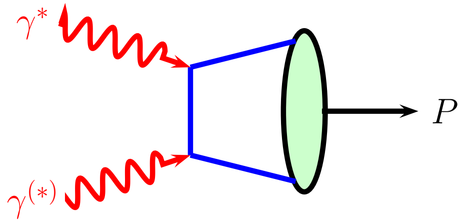
$\gamma^{(*)} p \to M p$




2h-DA

$\gamma^{(*)} \gamma \to B\bar{B}, M\bar{M}$

$p\bar{p} \to \gamma^{(*)}\gamma, \gamma M$

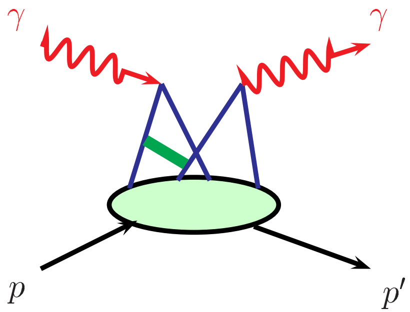



meson DA

$\gamma\pi(\eta, \eta')$ transition FF

other topologies (hard gluons required)

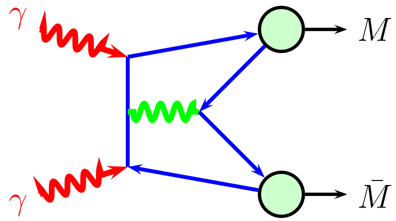
two (or more) active partons



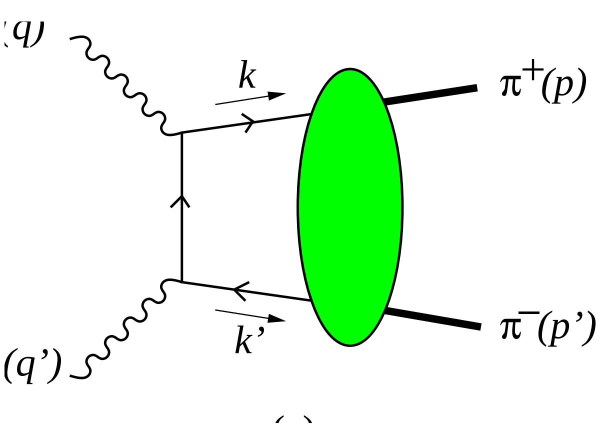

$\Longrightarrow$

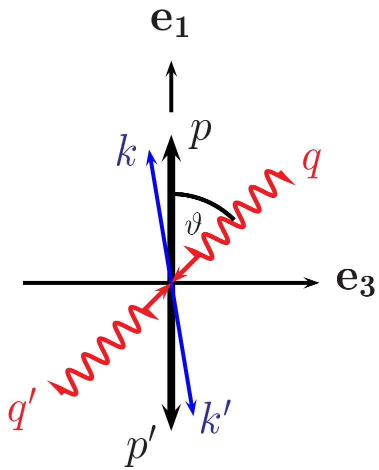
| | |
|---|---|
| valence | ERBL |
| quark appr. | fact. |

e.g. $\gamma\gamma \to M\bar{M}$



# $\gamma\gamma \to M\bar{M}$




physical picture:

hard process $\gamma\gamma \leftrightarrow q\overline{q}$

soft $q\overline{q} \leftrightarrow h\overline{h}$ transitions

$s, -t, -u \gg \Lambda^2$

$\Lambda$ typical hadronic scale of order $1\,\mathrm{GeV}$

sum over all possible parton conf.

work in symmetric frame: $p^+ = p'^+$ $\qquad \zeta = \frac{p^+}{(p+p')^+} = 1/2 \qquad z = \frac{k^+}{(p+p')^+}$

$(v^\pm = (v_0 \pm v_3)/\sqrt{2})$ $\qquad$ active parton off-shell momenta $k$, $k'$

to ensure soft $q\bar{q} \to \pi\pi$ transition: i) restricted transverse momenta $k_{\perp i}^2/z_i \sim \Lambda^2$

ii) all virtualities at the parton-hadron vertices are soft of order $\Lambda^2$

expand parton momenta around hadron momenta

$\Longrightarrow 2z-1, \sin\varphi \sim \Lambda^2/s$ $\qquad$ $\varphi$ orientation of active partons in 1-2 plane

$\varphi \simeq 0 : k \simeq p \quad k' \simeq p' \qquad \varphi \simeq \pi : k \simeq p' \quad k' \simeq p$

amplitudes ($\mu, \mu'$ photon helicities)

$$A_{\mu\mu'} = -\sum_q (ee_q)^2 \int \frac{d^4k}{\sqrt{k^+k'^+}} \mathcal{H}_{\mu\mu'}(k,k')\, S(k,k') + \text{axial current term}$$

soft matrix element: ($\pi\pi$ production in $\gamma\gamma$ annihilation is C even)

$$S = \frac{1}{2}\int \frac{d^4x}{(2\pi)^4} e^{-ikx} \langle \frac{\pi^+(p)\pi^-(p') + \pi^+(p')\pi^-(p)}{2} \mid T\bar{q}(x)\gamma^+ q(0) \mid 0\rangle$$

charge conjugation invariance: $S(k,k') = -S(k',k) \qquad \mathcal{H}(k,k') = -\mathcal{H}(k',k)$
two regions $k \simeq p$, $k \simeq p'$ are related through rotation by $\pi$ around 3-axis

Taylor expansion of $\gamma\gamma \to q\bar{q}$ kernel around 1-axis: ($\mathcal{H}_{\pm\pm} = 0$)

$$\mathcal{H}_{\pm\mp} = \underbrace{2(\sqrt{u/t} - \sqrt{t/u})}_{\sim 1/\sin\theta} - \underbrace{(z-\bar{z})(s/t + u/t)}_{\sim 1/\sin^2\theta} + \mathcal{O}((z-\bar{z})^2, \varphi^2)$$

leading term vanishes due to a conspiracy of charge conj. inv. and rotation

$\gamma\gamma \to \pi\pi$ special situation

conspiracy does not occur in (and leading term of $\mathcal{H}$ dominates):

$\gamma\gamma \to B\bar{B}$: region $k' \simeq p$ corresponds to antiquark hadronization into $B$
requires sea quarks with very high momentum fractions
unlikely to exist

space-like region, e.g. real Compton scattering - $\gamma\pi(p) \to \gamma\pi(p)$
regions $k^+ > 0$ $(\gamma q \to \gamma q)$ and $k^+ < 0$ $(\gamma\bar{q} \to \gamma\bar{q})$
related by charge conj. but not by rotation

$z - \bar{z}$ term is parametrically of same order as parton-off-shellness effects
we remain with on-shell approximation
our approach to $\gamma\gamma \to \pi\pi$ is to be considered as a model

# $\pi\pi$ DA, form factors, amplitudes

$$\Phi^q_{2\pi}(z,\zeta=1/2,s) \;=\; \int \frac{dx^-}{2\pi} e^{-iz(p+p')^+x^-} \langle \pi^+(p)\pi^-(p')|\bar{q}(x)\gamma^+ q(0)|0\rangle\Big|_{x=[0,x^-,0_\perp]}$$

$$R^q_{2\pi} = \frac{1}{2}\int_0^1 dz(z-\bar{z})\Phi^q_{\pi\bar{\pi}}(z,1/2,s) \qquad\qquad F^q_\pi = \int_0^1 dz\Phi^q_{2\pi}(z,1/2,s)$$

$$R_{2\pi} = e_u^2\, R^u_{2\pi} + e_d^2\, R^d_{2\pi} + e_s^2\, R^s_{2\pi} \qquad\qquad F_\pi = e_u F^u_\pi + e_d F^d_\pi$$

$$A_{\pm\mp} = -\frac{16\pi\alpha_{\rm elm}}{\sin^2\theta} R_{2\pi}(s)$$

$$\frac{d\sigma}{dt}(\gamma\gamma\to\pi\bar{\pi}) = \frac{8\pi\alpha^2_{\rm elm}}{s^4}\,\frac{1}{\sin^4\theta}|sR_{2\pi}(s)|^2$$

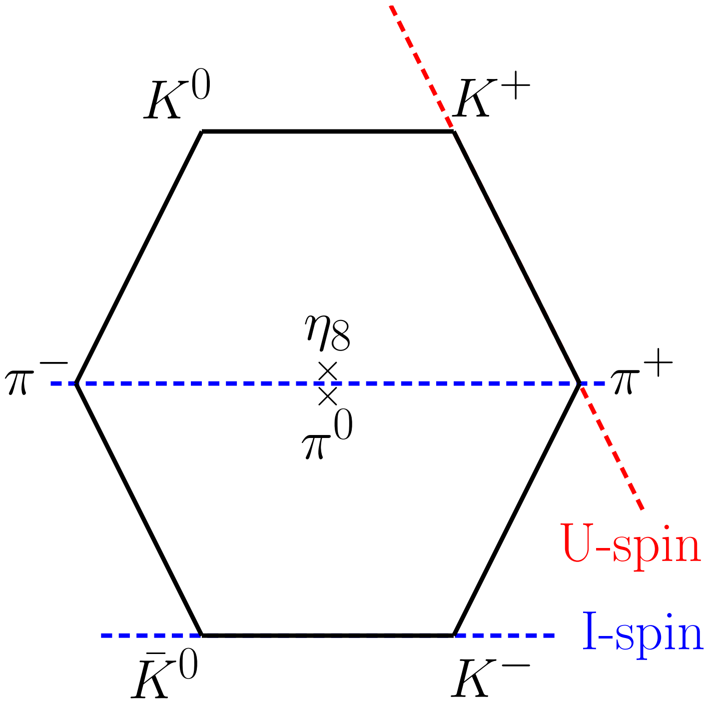
$$\sigma(\gamma\gamma\to\pi\bar{\pi}) \;=\; \int_{-0.6}^{0.6} d\cos\theta\frac{d\sigma}{d\cos\theta} \sim \frac{1}{s^3}\,|sR_{2\pi}|^2$$

generalization to $\pi \to M$ straightforward

# SU(3) flavor symmetry

SU(2) symmetries associated with $u \leftrightarrow d$ Isospin $u(d) \leftrightarrow s$ V(U)-spin

photon behaves as $U$-spin singlet: – $M\overline{M}$ couples to $U = 0$




and from dynamics:

only $q\bar{q}$ intermediate state

absence of $I = 2$ and $V = 2$:

$\Longrightarrow$ many relations among the $6 \times 3 = 18$ form factors
only two independent: $R^u_{2\pi}$, $R^s_{2\pi}$

$$R_{\pi^+\pi^-} = R_{\pi^0\pi^0} = R_{K^+K^-} = \tfrac{5}{9} R^u_{2\pi} + \tfrac{1}{9} R^s_{2\pi}$$ (smallest contr. from non-valence)

$$R_{K^0\overline{K}^0} = \tfrac{2}{9} R^u_{2\pi} + \tfrac{4}{9} R^s_{2\pi}$$ (strongest contr. from non-valence)

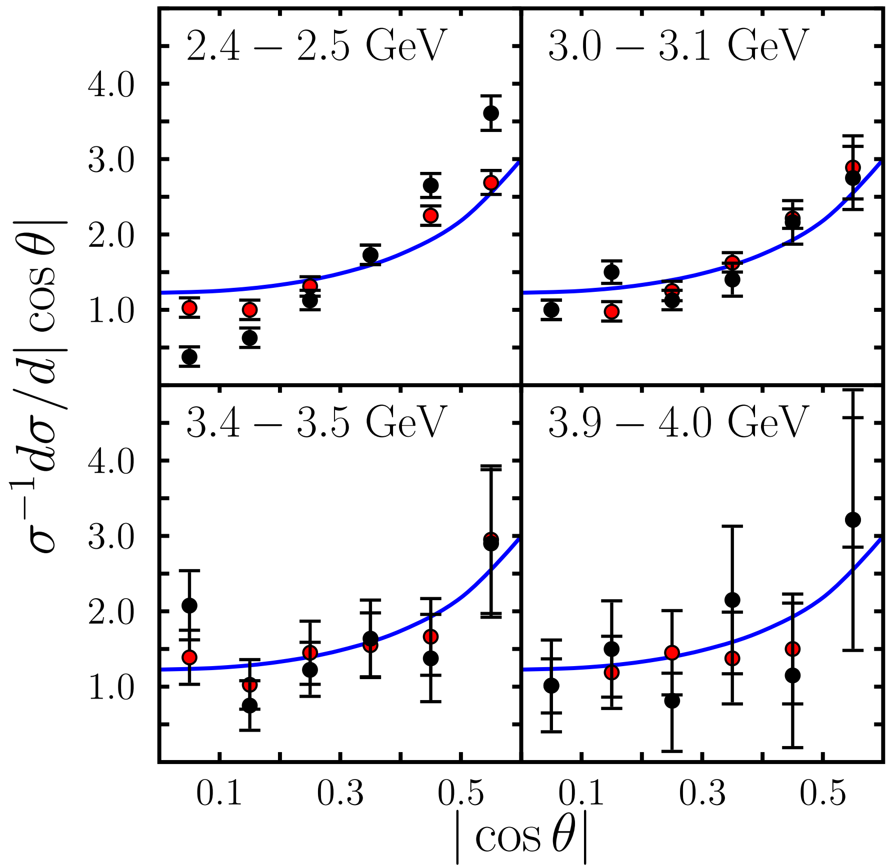
$$R_{\eta\pi^0} = \tfrac{1}{3\sqrt{3}} (R^u_{2\pi} - R^s_{2\pi}), \qquad R_{\eta\eta} = \tfrac{1}{3} (R^u_{2\pi} + R^s_{2\pi})$$

$R^u_{2\pi}$, $R^s_{2\pi}$ and rel. phase from cross sections on $K^0\overline{K}^0$, $\eta\pi^0$, $K^+K^-$
other channels predicted ($\pi^+\pi^-$, $\pi^0\pi^0$, $\eta\eta$)

# Probing the $\sin^{-4}\theta$ behavior

**BELLE**

$\gamma\gamma \to \pi^+\pi^-(\bullet), K^+K^-(\color{red}\bullet)$

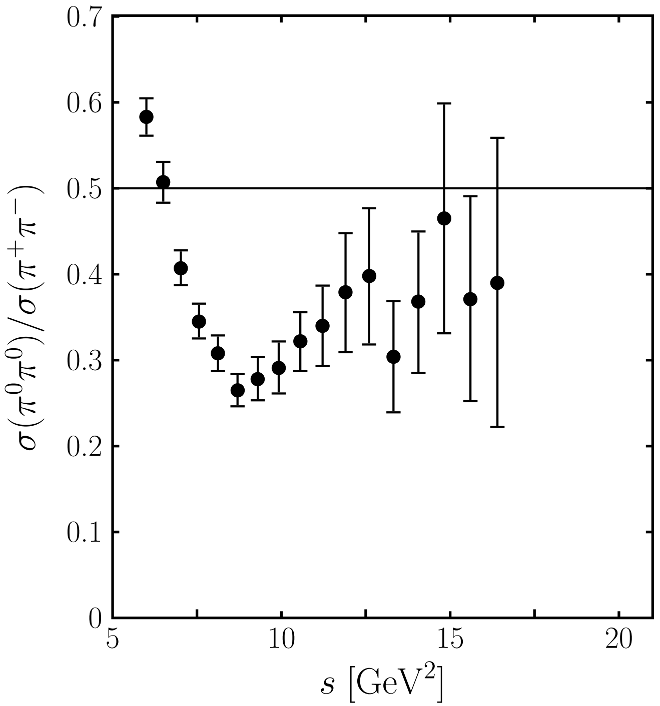



$\propto 1/\sin^4\theta$ for $s \gtrsim 9\,\mathrm{GeV}^2$

holds for other channels too

$\sigma(\pi^+\pi^-) \simeq \sigma(K^+K^-)$

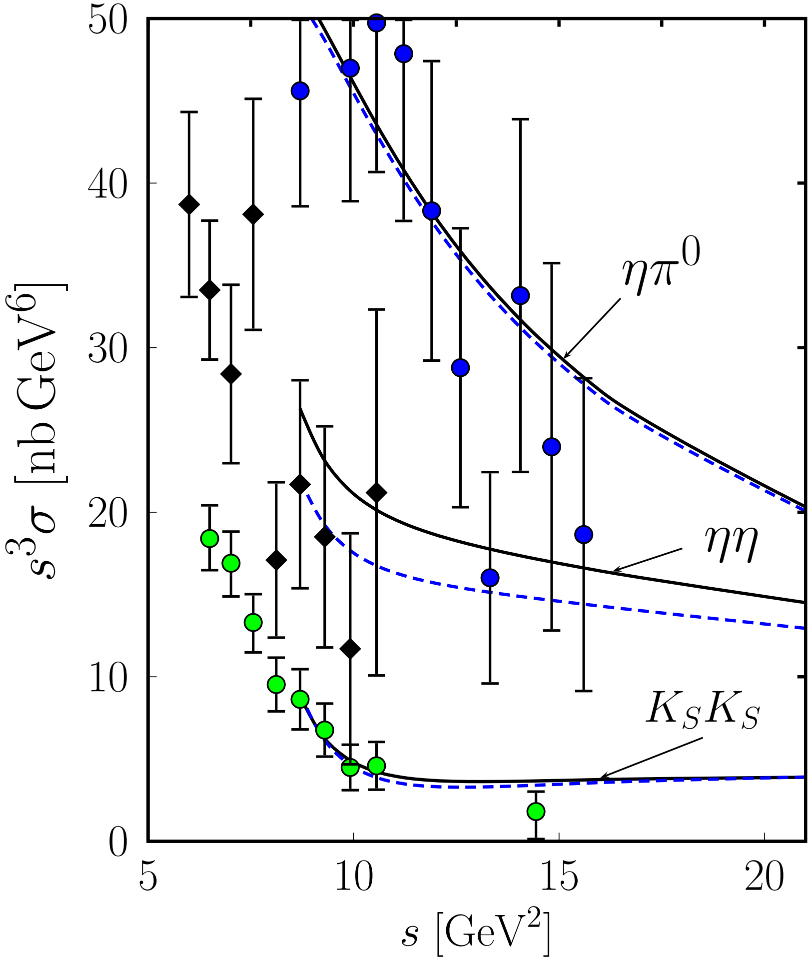
# $\pi^0\pi^0/\pi^+\pi^-$




$$A_{\pi^+\pi^-} = (\sqrt{2}A_{2\pi}^{I=0} + A_{2\pi}^{I=2})/\sqrt{6}$$
$$A_{\pi^0\pi^0} = (A_{2\pi}^{I=0} - \sqrt{2}A_{2\pi}^{I=2})/\sqrt{3}$$

consistent with dominance of $I = 0$
for large $s$
with little admixture of $I = 2$
(if in phase $A_2/A_0 < 0.11$)

# Results on cross sections




$-0.6 < \cos\theta < 0.6$

data: BELLE

$\eta = \eta_8$ (solid)

with mixing (dashed)

$\sigma(K^0\bar{K}^0) = 2\sigma(K_S K_S)$

# ERBL factorization

requires very large scales in order to hold (dramatic failures in normalizations of $\pi$ and proton FF, Compton scattering, $\gamma\gamma \to M\overline{M}, p\overline{p}$)

$\gamma\gamma \to M\overline{M}$: $\quad A \sim f_{M_1} f_{M_2} \int dx \Phi_{M_1}(x) \int dy \Phi_{M_2}(y) T(x, y, \theta)$

charged mesons $\quad d\sigma/dt \propto 1/\sin(\theta)^4$, $\quad \sigma \propto s^{-3}$

production of neutral mesons suppressed - bulk of ampl. $\sim (e_{q_1} - e_{q_2})^2$
explicite calculations (Brodsky-Lepage(80), Benayoun-Chernyak(90)):
$\pi^0\pi^0/\pi^+\pi^- \lesssim 0.05$ $\quad$ ($I = 0$ and $I = 2$ of comparable size)

according to Chernyak(06,09):
another dyn. mechanism required for neutral mesons:

like handbag but with only one quark between meson DAs plus additional gluon
light-cone sum rule estimate of principal behavior
$\sigma \propto s^{-5}$ (valid for highly asymmetric behavior?)

| | | |
|---|---|---|
| $\pi^+\pi^-$, $K^+K^-$: | Chernyak $n = 3$ | BELLE $n = 4.0 \pm 0.2 \pm 0.7$ $(3.7)$ |
| $\pi^0\pi^0$, $\eta\eta$: | $n = 5$ | $n = 4.0 \pm 0.2 \pm 0.2$ $(3.9)$ |
| $K^0K^0$, $\pi^0\eta$: | $n = 5$ | $n = 5.3 \pm 0.3 \pm 0.2$ $(5.3)$ |

Actual fits to all data do not exist as yet

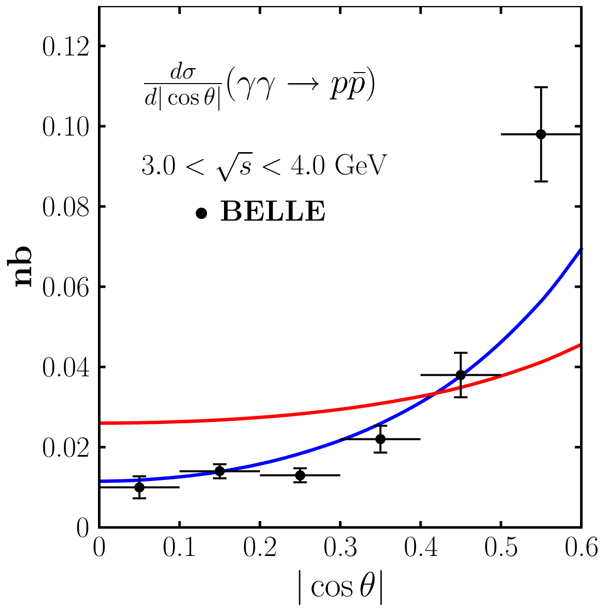
# $\gamma\gamma \leftrightarrow p\bar{p}$

$$\frac{d\sigma}{dt}(\gamma\gamma \leftrightarrow p\,\bar{p}\,) = \frac{4\pi\alpha_{\mathrm{elm}}^2}{s^6\sin^2\theta}\Big\{s^4 R_{\mathrm{eff}}^2 + \cos^2\theta\,\big|s^2 R_V(s)\big|^2\Big\}$$

$R_{\mathrm{eff}} = \sqrt{|R_A + R_P|^2 + \frac{s}{4m^2}|R_P|^2}$ $B\overline{B}$-DAs

Diehl et al (02), Weiss et al (02)

data from BELLE, CLEO, L3 more from PANDA? (e.g. $p\bar{p} \to \gamma M$)




$|\cos\theta| \leq 0.6$ BELLE hep-ex/0503006

$s^2 R_{\mathrm{eff}} = 2.9\,\mathrm{GeV}^4 (\frac{s}{10.4})^{-1.1}$

$s^2 R_V = 8.2\,\mathrm{GeV}^4 (\frac{s}{10.4})^{-1.1}$

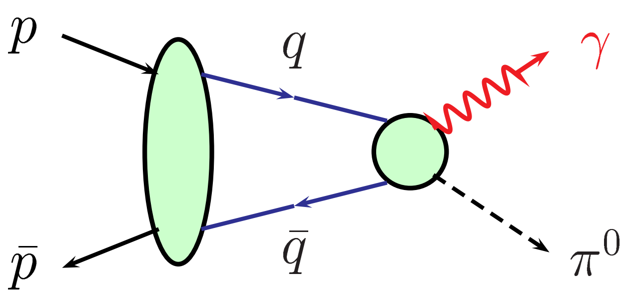
$R_P$ from $p\bar{p}$ helicity correlation

PANDA: test of factorization?

$\gamma\gamma \to q\bar{q}$ for point-like fermions:

$|R_V^p| = |R_A^p|; \quad R_P^p = 0: \quad \frac{d\hat{\sigma}}{dt} \propto \frac{1+\cos^2\theta}{\sin^2\theta}$

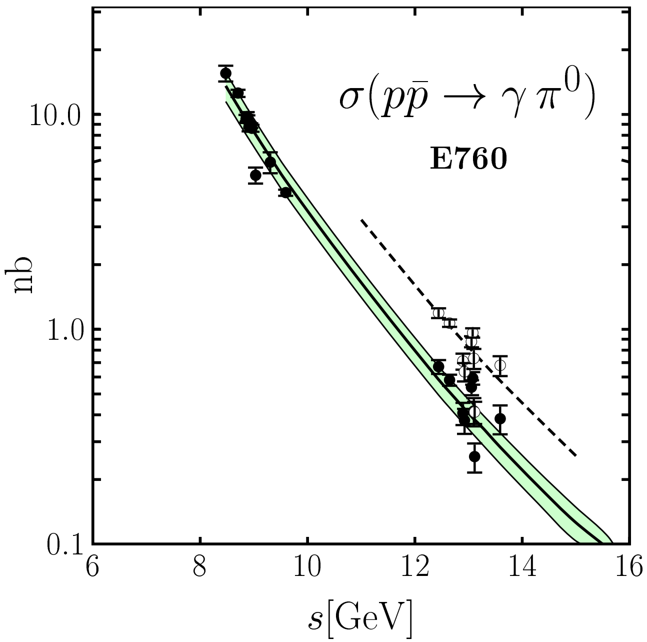
$p\bar{p} \to \gamma\pi^0$

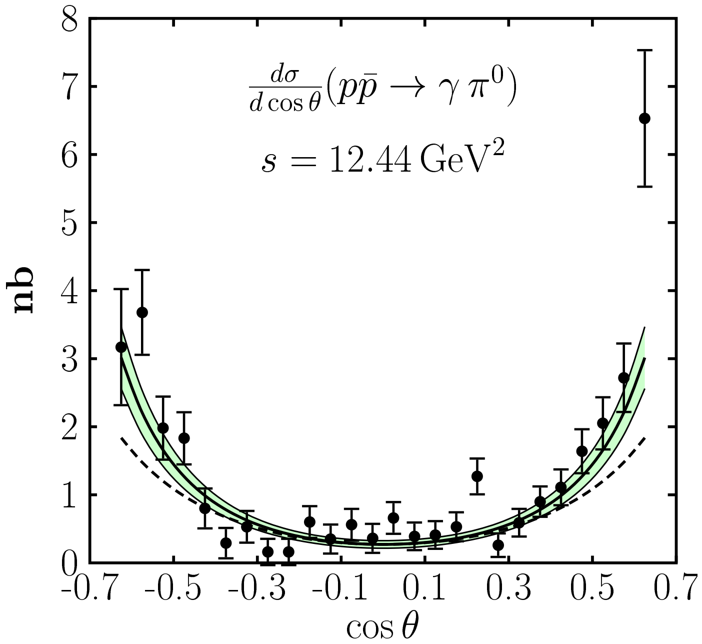



K.-Schäfer (05)

$$\frac{d\sigma}{d\cos\theta} = \frac{\alpha_{\rm elm}}{4s^6}\,\frac{|a|^2}{\sin^4\theta} \times \left[|s^2 R_{\rm eff}^{\pi^0}|^2 + \cos^2\theta |s^2 R_V^{\pi^0}|^2\right]$$

$R_i^\gamma \Rightarrow R_i^{\pi^0}$ $\quad a$ pert. constant



# Summary

- I presented a QCD inspired model for $\gamma\gamma \to M\bar{M}$ which is based on factorization into $\gamma\gamma \to q\bar{q}$ and 2-meson DAs
- Flavor symmetry combined with the fact that the intermediate $q\bar{q}$ state allows only $I = 0, 1$ leads to many relations among the amplitudes for the pseudoscalar channels; the soft physics is encoded in only two independent form factors
- The BELLE data on $\gamma\gamma \to M\bar{M}$ can be described very well for $s \gtrsim 9\,\mathrm{GeV}^2$.
- The approach has been extended to $B\bar{B}$ channels like $p\bar{p} \leftrightarrow \gamma\gamma$, $p\bar{p} \to \gamma M$ (PANDA)