S-P wave interference in the K+K- photoproduction on hydrogen

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This talk gives a brief summary of the results published in
Eur. Phys. J. **C34**:335-344, 2004 by Ł. B, L. Leśniak, A.P. Szczepaniak,
also available as hep-ph/0308267 preprint.

Plan:

1. motivation,
2. experimental results,
3. model,
4. results of the fits,
5. conclusions.

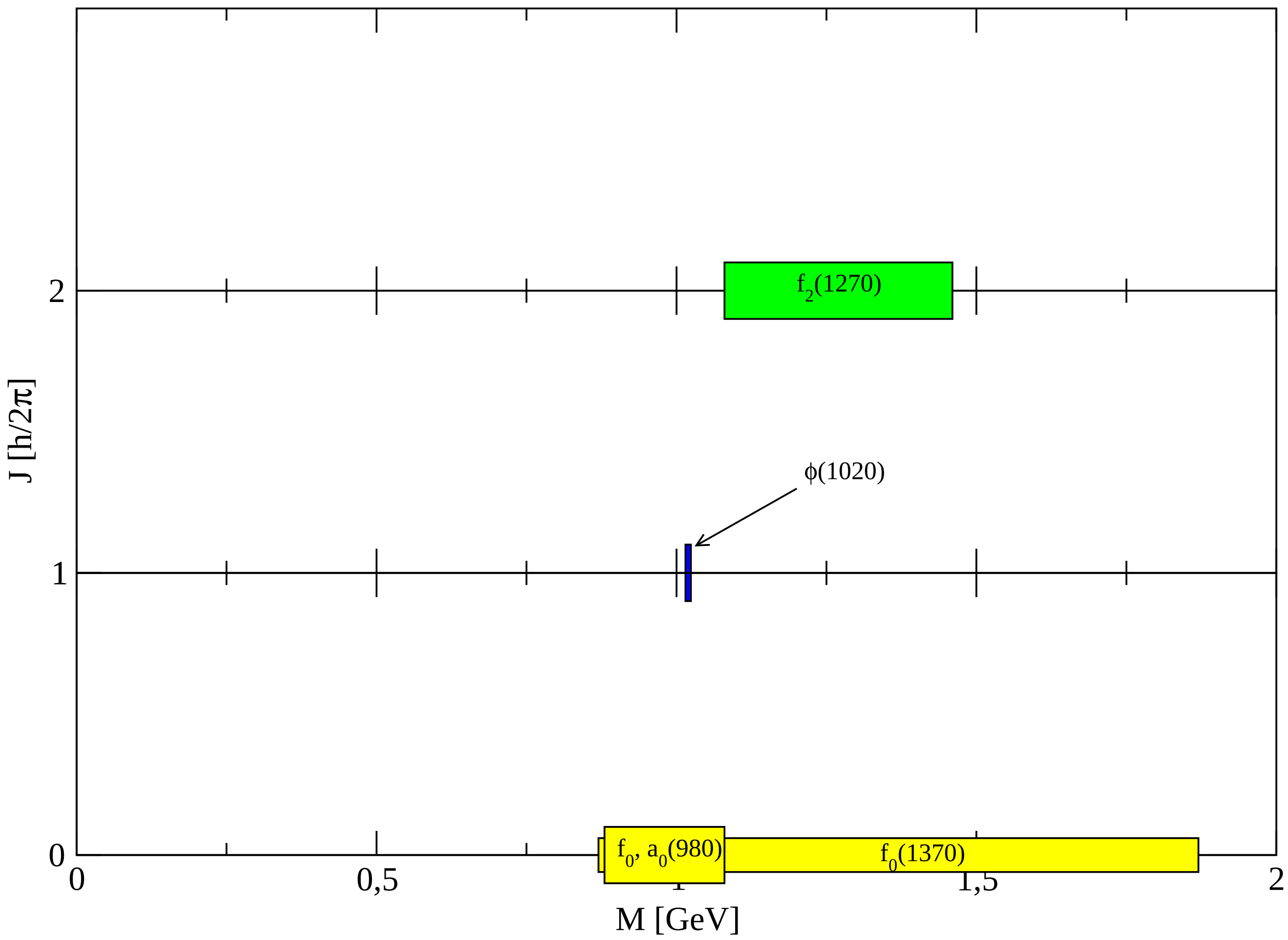
1. Motivation:

- determination of the resonant S-wave contribution ($a_0(980)$ and $f_0(980)$) in the $\gamma p \to K^+K^-p$ reaction near the K^+K^- threshold,
- explanation of a large experimental uncertainty the S-wave K^+K^- photoproduction cross section, ranging from 3 nb to 100 nb in the range around the mass of $\phi(1020)$,
- explanation of the asymmetry in the kaon angular distributions.

2. Experimental results

We base on the experimental results obtained in the end of seventies at DESY (Behrend et al., 1978) and in the beginning of eighties at Daresbury (Barber et al., 1982).
We examine the $\gamma p \to K^+K^-p$ reaction at two photon energies:
I. E_γ=4 GeV; (-t $<$ 1.5 GeV^2; 0.997 GeV $< M_{K\overline{K}} <$ 1.042 GeV)
(Barber),
II. E_γ=5.65 GeV; (-t $<$ 0.2 GeV^2; 1.005 GeV $< M_{K\overline{K}} <$ 1.045 GeV)
(Behrend).

Resonances in K^+K^- channel



3. Model

Amplitudes:

$$T_{\lambda_\gamma \lambda \lambda'}(t, M_{K\overline{K}}, \Omega) = \sum_{L=0,1;M} T^L_{\lambda_\gamma,\lambda,\lambda';M}(t, M_{K\overline{K}}) Y^L_M(\Omega),$$

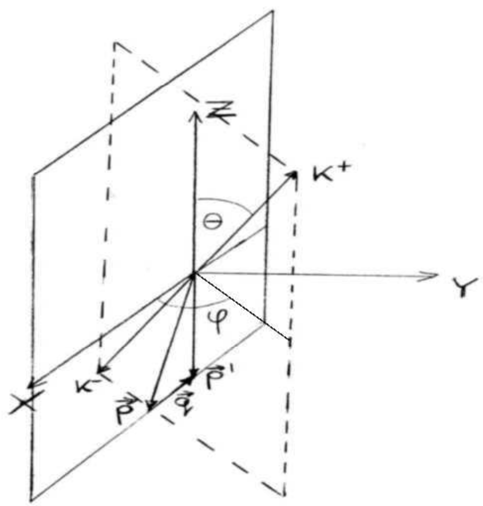
where L, M denote the K^+K^- angular momentum and its projection on the helicity axis,

$\lambda_\gamma, \lambda, \lambda'$ - helicities of the photon, incoming and outgoing proton,

q, p, p' - momenta of the photon, incoming and outgoing proton,

t - momentum transfer squared,

$M_{K\overline{K}}$ - $K\overline{K}$ effective mass.



In total we have $2 \times 2 \times 2 \times 3 = 24$ (P-wave) + $2 \times 2 \times 2 = 8$ (S-wave) amplitudes, but only 16 are independent according to the parity conservation:

$$T^J_{-M}(-\lambda_\gamma, -s_1, -s_2) = (-1)^{M-s_2-\lambda_\gamma+s_1} T^J_M(\lambda_\gamma, s_1, s_2)$$

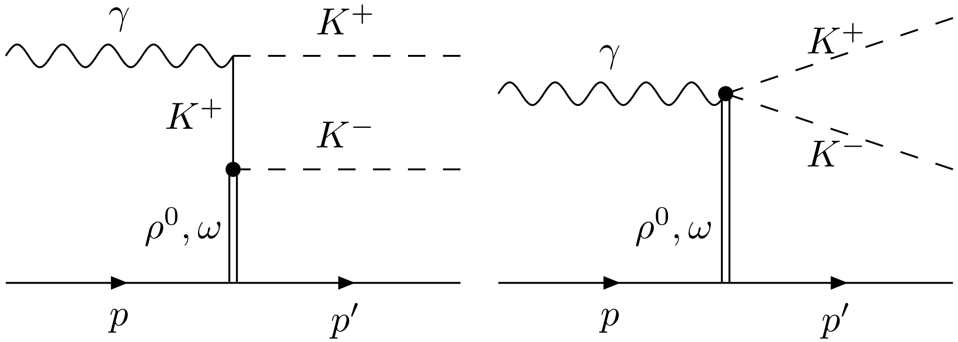
Thus we can take λ_γ=+1 as a "reference" helicity and label the K^+K^- (or ϕ) helicities as:

- non-flip ($M = +1$),
- single flip (M=0),
- double flip ($M = -1$).

Production mechanism

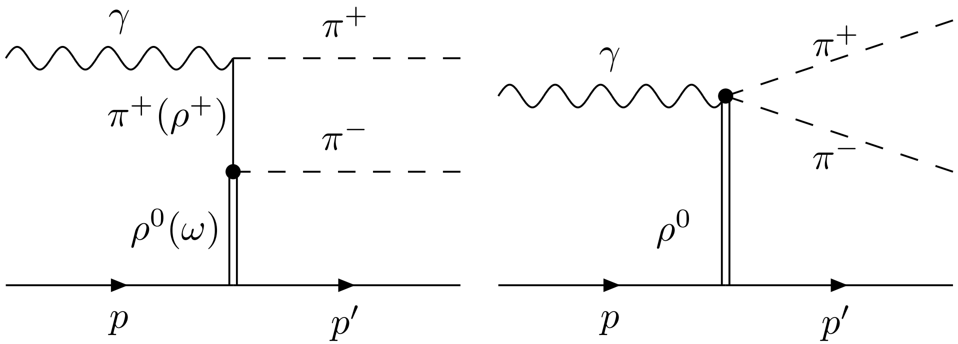
Diagrams for S-wave Born amplitudes (PR**C58**,2, C-R. Ji, et al.):

a)



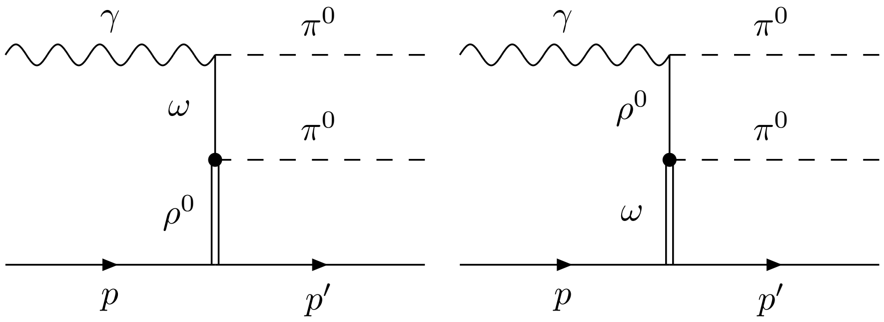
Also the graphs with $K^+ \leftrightarrow K^-$ (altogether 6 graphs).

b)

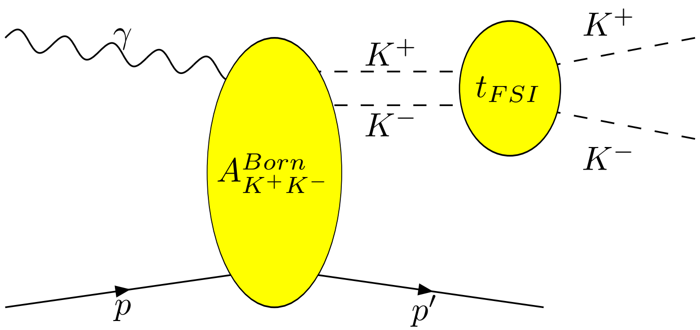


Also the graphs with $\pi^+ \leftrightarrow \pi^-$ and $\rho^+ \leftrightarrow \rho^-$(altogether 5 graphs).

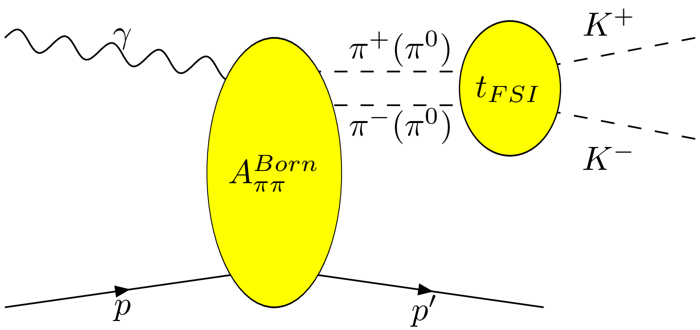
Graphs for double neutral pion prodution.



The final state interactions were also accounted for, with $\pi^+\pi^-$ and $\pi^0\pi^0$ intermediate states and the K^+K^- elastic rescattering.



Elastic K^+K^- rescattering



Inelastic $\pi\pi \to K^+K^-$ transition

In the S-wave t-channel exchanged particles we have used either normal:

$$\frac{1}{t-m^2},$$

where m is the mass of exchanged meson

or Regge propagators

$$-[1-e^{-i\pi\alpha(t)}]\Gamma(1-\alpha(t))(\alpha' s)^{\alpha(t)}/(2s^{\alpha_0})$$

The S-wave amplitude parameterization:

1. Isospin decomposition

$$A^S(I)=\frac{1}{2}[A^S(I=0)+A^S(I=1)]$$

Isoscalar ($f_0(980)$) and isovector ($a_0(980)$) parts.

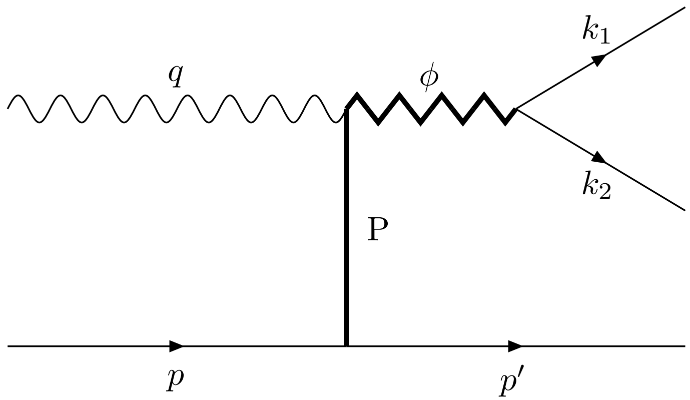
2. FSI factor.

$$A^S(I)_f=\sum_{j=\pi\pi,K\overline{K}} A^B_j(I)F_{jf}(I)\text{ , where } F_{jf}(I)\sim\frac{1}{2}[\delta_{jf}+S_{jf}(I)]$$

$$S(I=0)=\begin{pmatrix} \eta e^{2i\delta^{I=0}_{\pi\pi}} & i\sqrt(1-\eta^2)e^{i(\delta^{I=0}_{\pi\pi}+\delta^{I=0}_{K\overline{K}})} \\ i\sqrt(1-\eta^2)e^{i(\delta^{I=0}_{\pi\pi}+\delta^{I=0}_{K\overline{K}})} & \eta e^{2i\delta^{I=0}_{K\overline{K}}} \end{pmatrix}$$

S(I=1) is similar.

In the P-wave we have assumed the Pomeron exchange (L. Leśniak, A. P. Szczepaniak APP B34,2003).



Construction of the amplitude:

$$T^{S,P}_{\lambda_\gamma,\lambda,\lambda',M} = \overline{u}(p',\lambda')J^{S,P}_{\mu}{}_{M}\varepsilon^{\mu}(q,\lambda_\gamma)u(p,\lambda)$$

where

q – 4-momentum of the photon,

$$J^P_\mu = \frac{iF(t)}{M^2_\phi - M^2_{K\overline{K}} - iM_\phi\Gamma_\phi}[\gamma^\nu q_\nu (k_1-k_2)^\mu - q^\nu (k_1-k_2)_\nu \gamma^\mu].$$

$F(t)$ is parameterised to properly reproduce the $d\sigma/dt$ for both energies (4 GeV and 5.65 GeV).

Generally:
S- and P-wave amplitudes are Lorentz, gauge and parity invariant.

We have used the moments of the angular distribution to compare the model with experimental data:

$$Y_0^0 = \frac{\mathcal{N}}{\sqrt{4\pi}}(|S|^2 + |P_{-1}|^2 + |P_0|^2 + |P_1|^2),$$

$$Y_0^1 = \frac{\mathcal{N}}{\sqrt{4\pi}}(SP_0^* + S^*P_0), \quad Y_1^1 = \frac{\mathcal{N}}{\sqrt{4\pi}}(P_1S^* - SP_{-1}^*),$$

$$Y_0^2 = \frac{\mathcal{N}}{\sqrt{4\pi}}\sqrt{\frac{1}{5}}(2|P_0|^2 - |P_1|^2 - |P_{-1}|^2),$$

$$Y_1^2 = \frac{\mathcal{N}}{\sqrt{4\pi}}\sqrt{\frac{3}{5}}(P_1P_0^* - P_0P_{-1}^*),$$

$$Y_2^2 = \frac{\mathcal{N}}{\sqrt{4\pi}}\sqrt{\frac{6}{5}}(-P_1P_{-1}^*).$$

where
$\mathcal{N}$-normalization factor.

Phenomenological input

We have treated relative phases and strenths as phenomenological parameters.

$$S \to C_{00} e^{i\varphi_{00}} S,$$

$$P_0 \to C_{10} e^{i\varphi_{10}} P_0, \quad P_{1,-1} \to C_{11} e^{i\varphi_{11}} P_{1,-1}.$$

Moreover we have used the linear parameterization for the background (as a background we consider a contribution from misidentified pions and higher partial waves):

$$\langle Y_M^L \rangle_b = v_M^L \frac{d\sigma}{dM_{K\overline{K}}} \quad \text{Barber's data},$$

$$\langle Y_M^L \rangle_b = \beta_M^L (M - M_{thr}) \quad \text{Behrend's data},$$

where M_{thr} is $K\overline{K}$ threshold mass.

Altogether we have

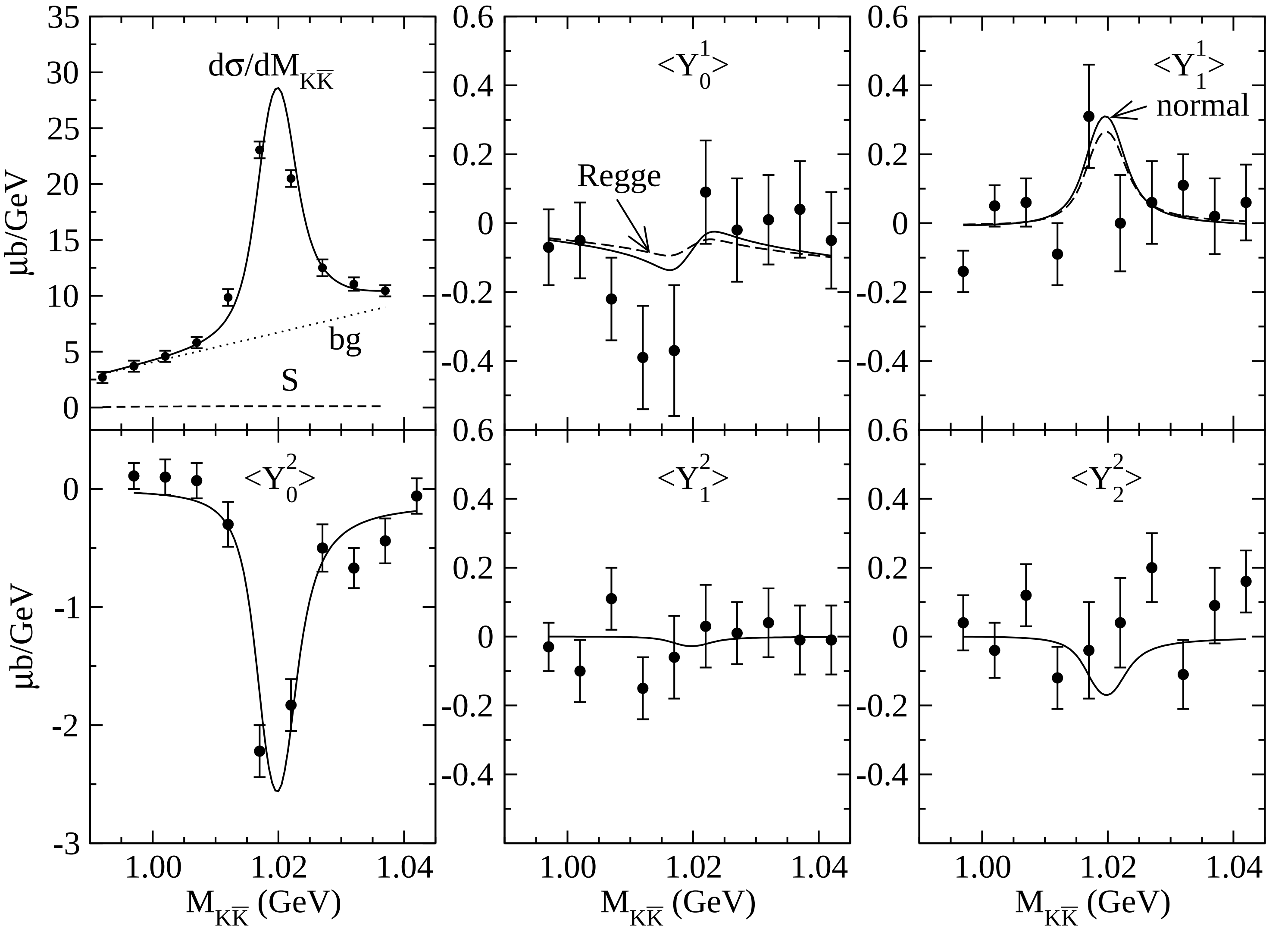
9 parameters for E_γ=4 GeV (Barber)

and

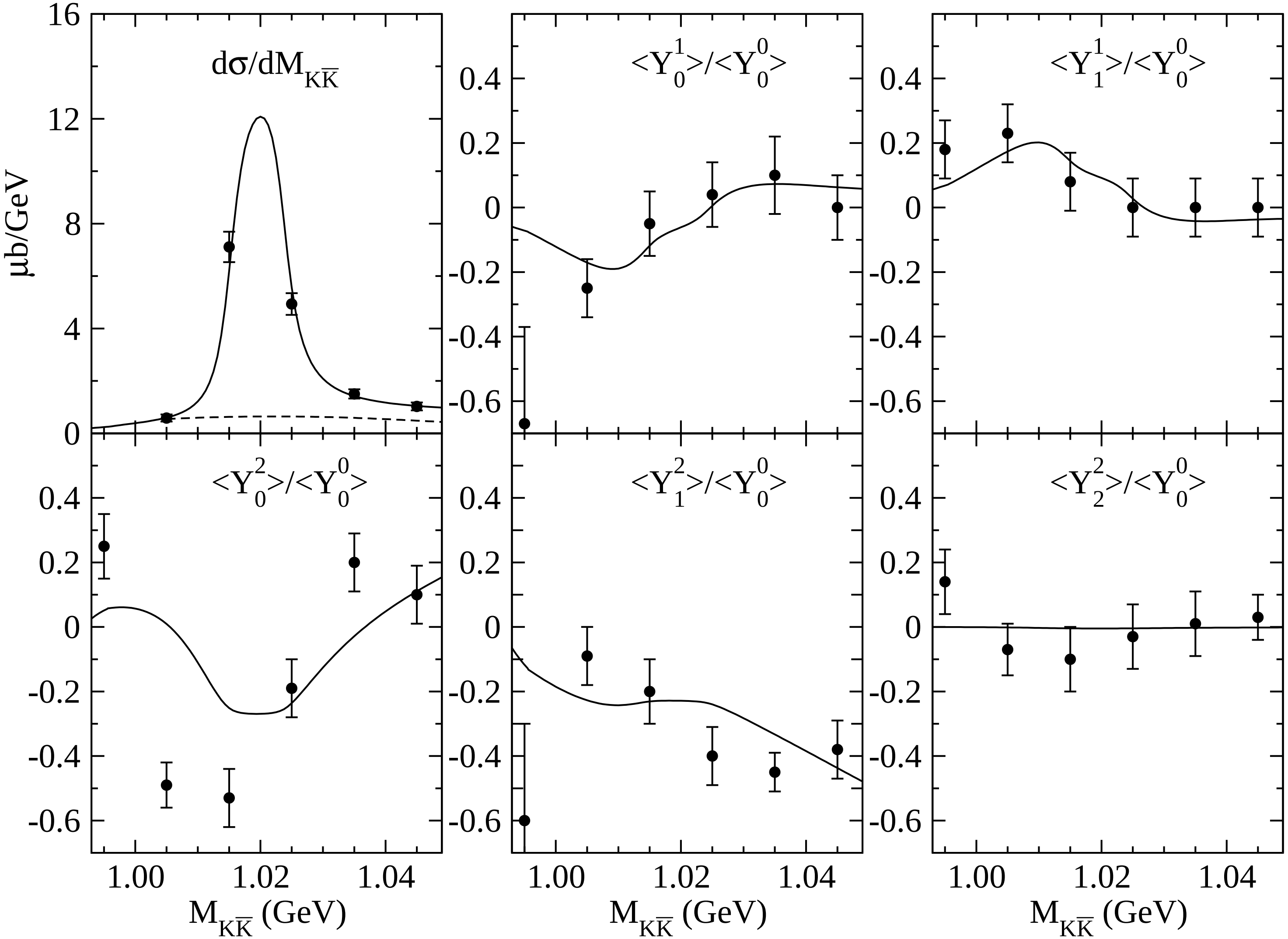
8 parameters for E_γ=5.65 GeV (Behrend).

4. Results of the fits (cross sections in nb)

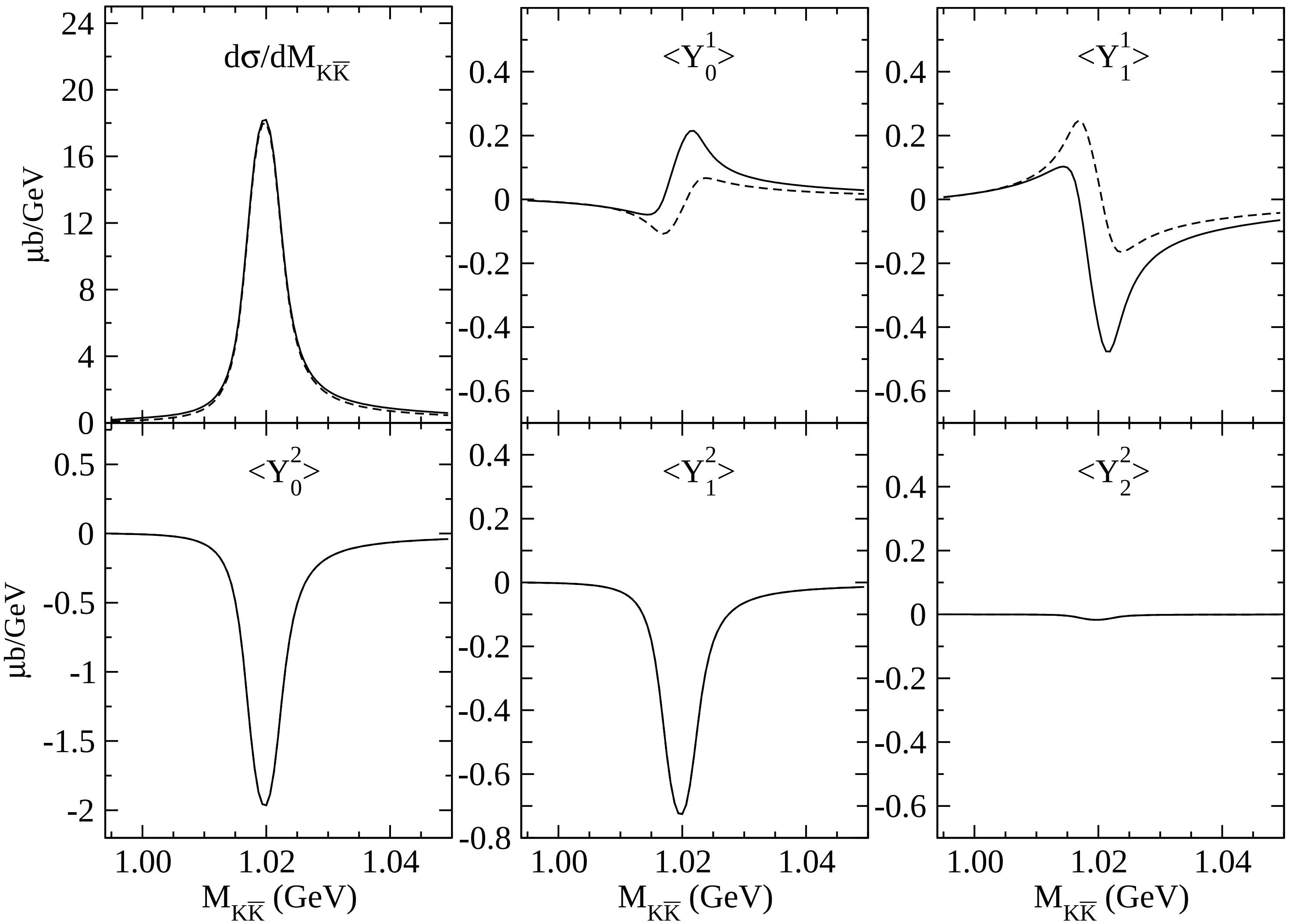
photon energy	4 GeV		5.65 GeV	
S-wave propagator	normal	Regge	normal	Regge
P-waves	218.4 ± 39.5		120.5 ± 9.4	
P_0-wave	$6.4^{+5.5}_{-4.8}$	$4.7^{+5.7}_{-4.5}$	$13.8^{+5.3}_{-4.7}$	$14.0^{+5.3}_{-4.8}$
S-wave	$4.9^{+5.8}_{-3.6}$	$4.3^{+6.6}_{-3.6}$	$7.0^{+6.8}_{-4.4}$	$6.8^{+6.6}_{-4.3}$
background	$299.4^{+10.0}_{-10.4}$	$300.0^{+10.0}_{-10.7}$	$4.5^{+4.3}_{-6.1}$	$4.7^{+4.2}_{-5.8}$
$\|t\|_{max}$	1.5 GeV^2		0.2 GeV^2	
$M_{K\overline{K}}$ range	(0.997,1.042) GeV		(1.01,1.03) GeV	



Mass distribution and moments at E_γ=4 GeV.



Mass distribution and moments at E_γ=5.65 GeV.



Prediction for a mass distribution and moments at E_γ=8 GeV (a value designed for future energy upgraded photon facility at JLab).

5. Conclusions

- The uncertainty concerning the magnitude of the S-wave contribution has been removed: our fit gives the S-wave cross section in the range of 4 to 7 nb.
- The model properly describes the K^+K^- mass distribution and the moments (also other observables).
- The resonant S-wave ($f_0(980)$ and $a_0(980)$) considerably affects the angular distribution of outgoing kaons.

Ł. Bibrzycki, L. Leśniak, A.P. Szczepaniak, Eur. Phys. J.**C34**:335-344, 2004
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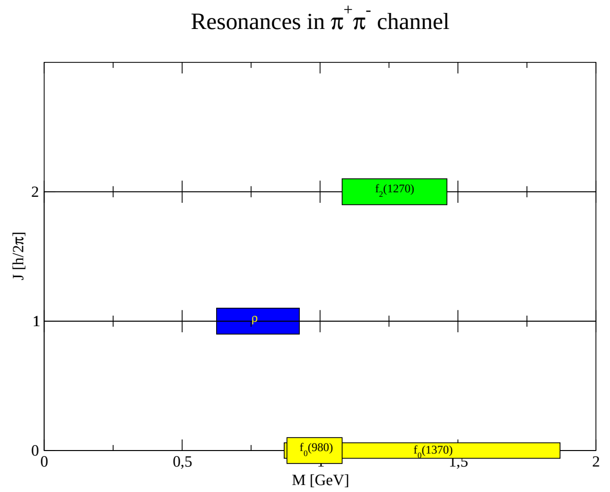
Outlook

What about a $\pi^+\pi^-$ channel...?



There are some indications that for a $\pi^+\pi^-$ channel an $f_2(1270)$ resonance may in fact participate in partial wave interference.

ρ^0 tail and the S-wave $\pi^+\pi^-$ production from the narrow $f_0(980)$ resonance. Moreover, in the $f_2(1270)$ meson region, the data suggest a sign change caused by the interference between the ρ^0 upper tail and the f_2 (D-wave).

The Legendre moment $\langle P_3 \rangle$ is sensitive only to the interference of P-wave and D-wave states in $\pi^+\pi^-$ pro-

HERMES Collaboration (A. Airapetian et al.) Phys.Lett.B599:212-222,2004