Nikolay Achasov, Alexey Kiselev

Sobolev Institute for Mathematics, Novosibirsk

Comparative inelastic production of the scalar and tensor mesons in $\gamma\gamma^*$ collisions

Light scalar mesons

• Nonet of light scalar mesons: $a_0(980)$, $f_0(980)$, $\sigma(600), \kappa(800)$

• Were discovered ~ 50 years ago and became hard problem for the naive quark model from the outset

• Elucidation of their nature can shed light on confinement and the chiral symmetry realization way in the low energy region

• Perturbation theory and sum rules don't work

• The $\sigma(600)$, $a_0(980)$, and $f_0(980)$ are studied in $\phi \to S\gamma$ decays, $\pi\pi$ scattering, $\gamma\gamma \to \pi\pi$, $\eta\pi^0$ and other processes

Light scalars in $\gamma\gamma$ collisions

Let's $S = \sigma(600)$, $a_0(980)$, $f_0(980)$ **and** $T = a_2(1320)$, $f_2(1270)$.

In the $q\bar{q}$ **model** $\Gamma_{S\to\gamma\gamma}$ **are originated from direct** $S\gamma\gamma$ **coupling. From the experimental results**

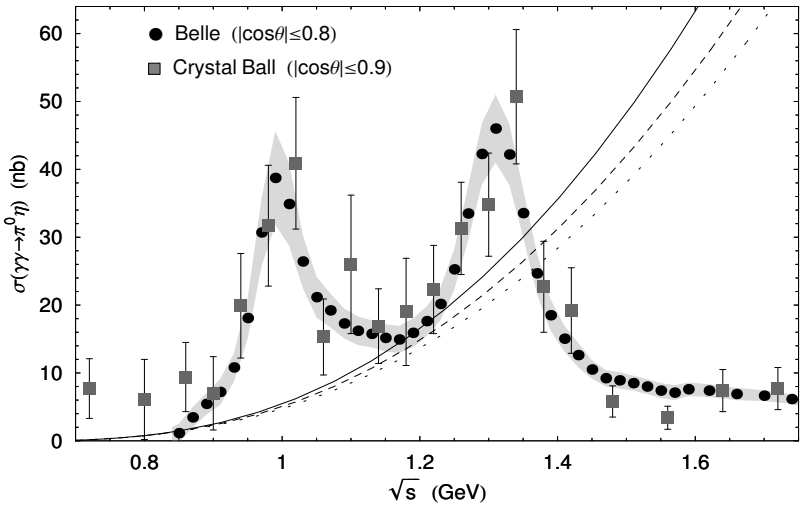
$$\Gamma_{f_2(1270)\to\gamma\gamma} \approx 3 \text{ keV}, \ \Gamma_{a_2(1320)\to\gamma\gamma} \approx 1 \text{ keV}$$

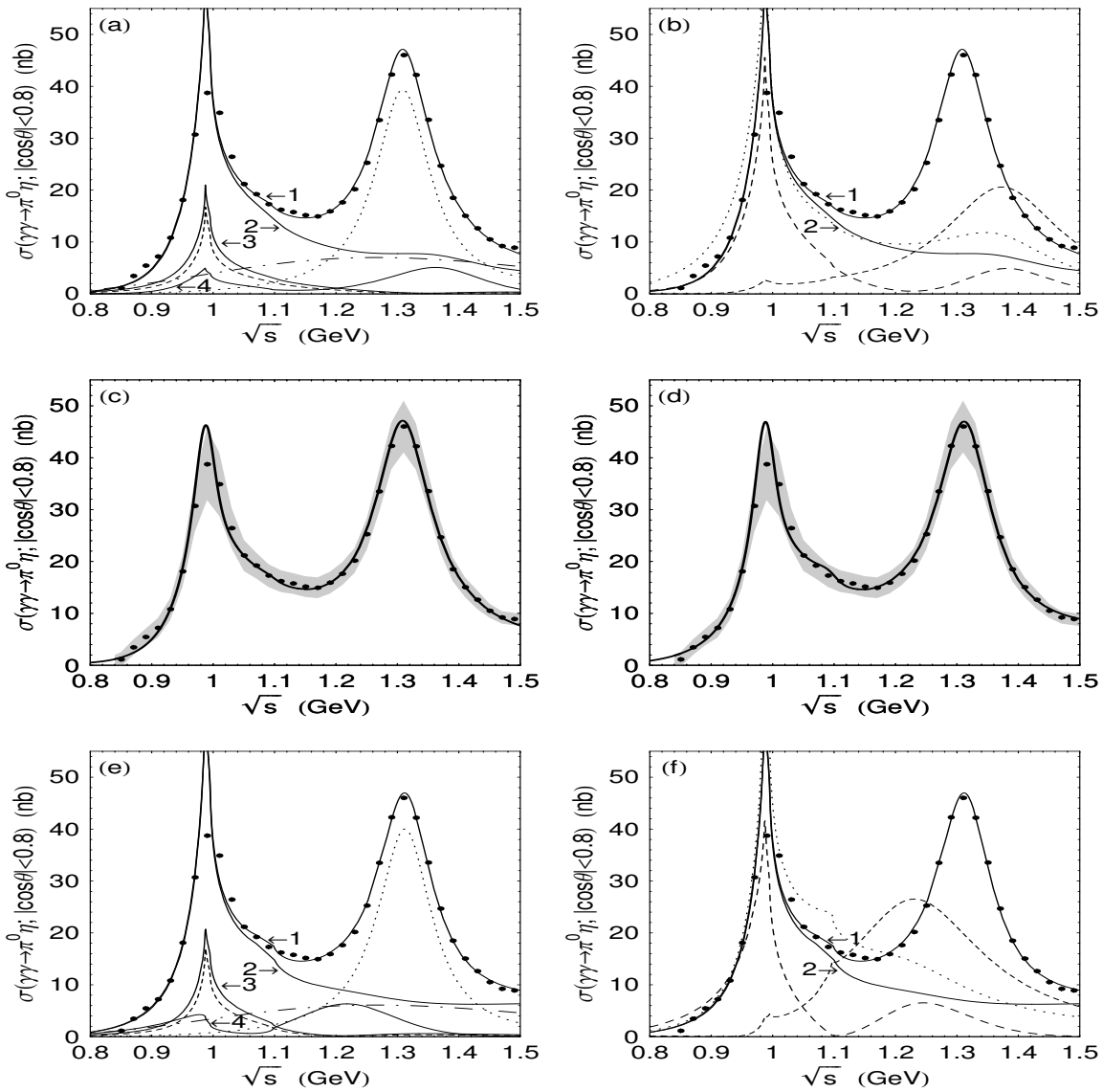
it was found $\Gamma_{f_0(980)\to\gamma\gamma} \geq 3.4$ **keV**, $\Gamma_{a_0(980)\to\gamma\gamma} \geq 1.3$ **keV**.

Four quark model: $\Gamma_{f_0(980)\to\gamma\gamma} \sim \Gamma_{a_0(980)\to\gamma\gamma} \sim 0.27$ **keV**
(Achasov, Devyanin, Shestakov, 1982)
These widths are caused by rescatterings:
$f_0 \to K^+K^- + \pi^+\pi^- \to \gamma\gamma$, $a_0 \to K^+K^- + \eta\pi^0 + \eta'\pi^0 \to \gamma\gamma$

The Belle data (2003-2009)

The data are extracted from the $e^+e^- \to e^+e^-\gamma\gamma \to e^+e^-\eta\pi^0$, $e^+e^-\pi^0\pi^0$ reactions. The sample is 100 fb^{-1} (hundreds thousand events). It was shown that these data supports the four quark model of light scalars $\sigma(600)$, $a_0(980)$, $f_0(980)$ (Achasov, Shestakov, 2005-2010).

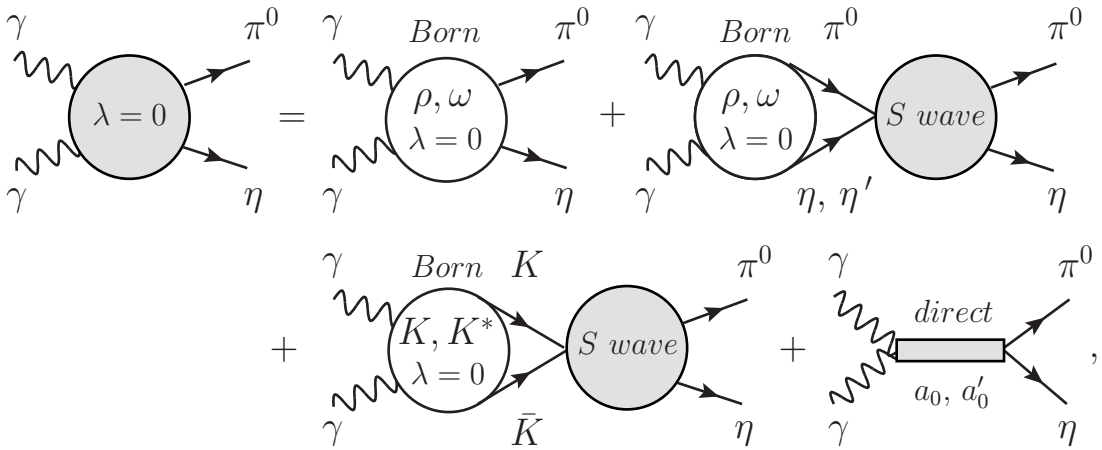


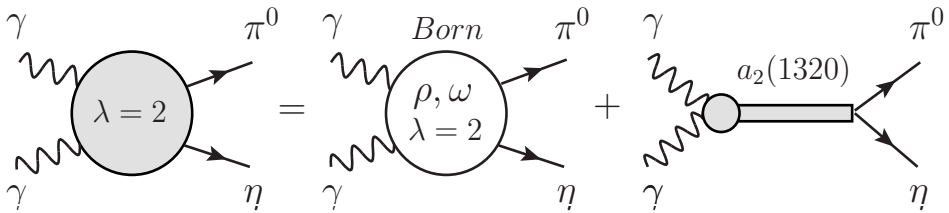

(a)
(b)
(c)
(d)
(e)
(f)
σ(γγ→π⁰η; |cosθ|<0.8) (nb)
√s (GeV)
←1
2→
←3
←4

Data description

$\sigma(\gamma\gamma \to \eta\pi^0) = \sigma_0 + \sigma_2$, **where**

$$\sigma_\lambda = \frac{\rho_{\pi\eta}(s)}{64\pi s} \int |M_\lambda|^2 d\cos\theta \; ; \; \rho_{\pi\eta}(s) = \sqrt{(1 - \frac{(m_\eta + m_\pi)^2}{s})(1 - \frac{(m_\eta - m_\pi)^2}{s})}$$





$$
\begin{aligned}
M_0(\gamma\gamma \to \pi^0\eta; s, \theta) &= M_0^{\mathbf{Born}\,V}(\gamma\gamma \to \pi^0\eta; s, \theta) \\
&+ \widetilde{I}^V_{\pi^0\eta}(s)\, T_{\pi^0\eta\to\pi^0\eta}(s) + \widetilde{I}^V_{\pi^0\eta'}(s)\, T_{\pi^0\eta'\to\pi^0\eta}(s) \\
&+ \left(\widetilde{I}^{K^{*+}}_{K^+K^-}(s) - \widetilde{I}^{K^{*0}}_{K^0\bar{K}^0}(s) + \widetilde{I}^{K^+}_{K^+K^-}(s, x_1)\right) \\
&\times T_{K^+K^-\to\pi^0\eta}(s) + M_{\mathbf{res}}^{\mathbf{direct}}(s),
\end{aligned} \tag{1}
$$

$$
\begin{aligned}
M_2(\gamma\gamma \to \pi^0\eta; s, \theta) &= M_2^{\mathbf{Born}\,V}(\gamma\gamma \to \pi^0\eta; s, \theta) \\
&+ 80\pi d^2_{20}(\theta) M_{\gamma\gamma\to a_2(1320)\to\pi^0\eta}(s),
\end{aligned} \tag{2}
$$

$$d^2_{20}(\theta) = (\sqrt{6}/4)\sin^2\theta$$

$$T_{\eta\pi^0\to\eta\pi^0} = \frac{e^{2i\delta_B^{\eta\pi}} - 1}{2i\rho_{\eta\pi}(m)} + e^{2i\delta_B^{\eta\pi}} \sum_{S,S'} \frac{g_{S\eta\pi}\, G^{-1}_{SS'}\, g_{S'\pi\pi}}{16\pi}$$

$$G_{SS'}(m) = \begin{pmatrix} D_{a_0'}(m) & -\Pi_{a_0 a_0'}(m) \\ -\Pi_{a_0 a_0'}(m) & D_{a_0}(m) \end{pmatrix}$$

$$T_{ab\to cd} = e^{i\delta_B^{ab}} e^{i\delta_B^{cd}} T^{res}_{ab\to cd}$$

$$T^{res}_{ab\to cd} = \sum_{S,S'} \frac{g_{Sab}\, G^{-1}_{SS'}\, g_{S'cd}}{16\pi}$$

$$S, S' = a_0, a_0'$$

Kaon form factor

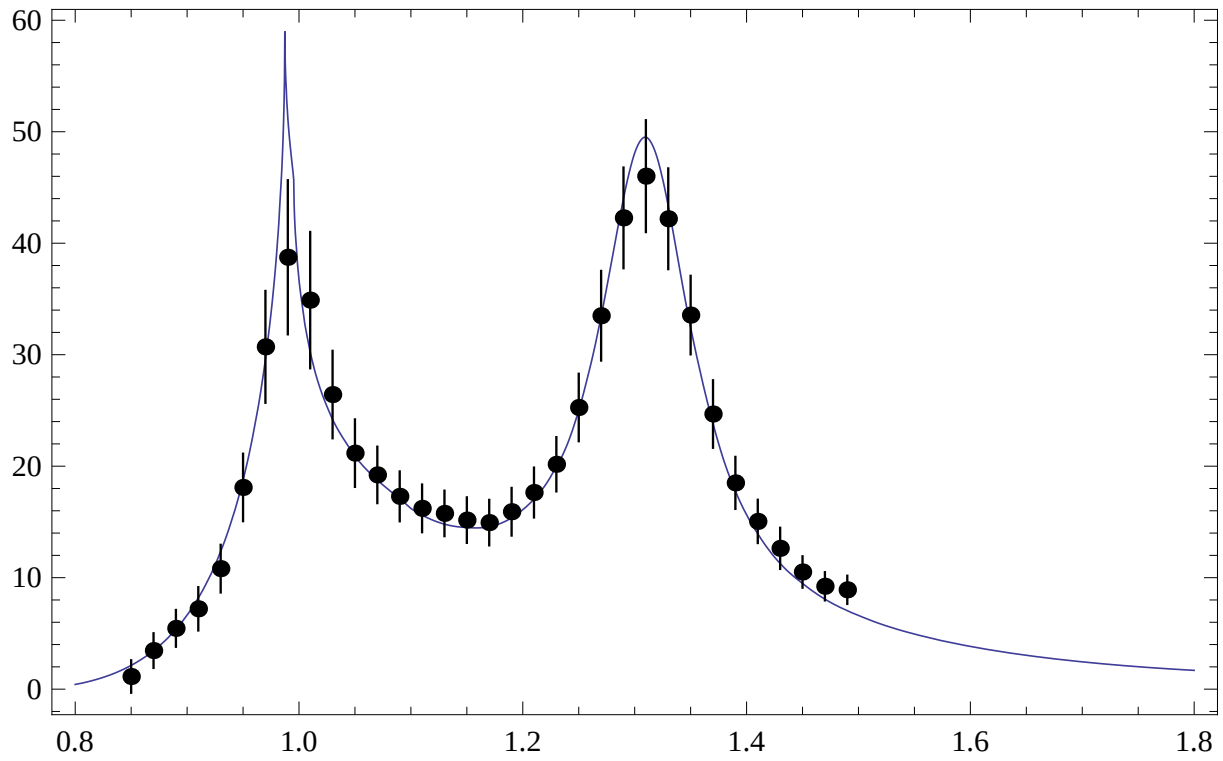
$$M_{00}^{Born\,K^+}(s',x_1) = 4\pi\alpha\frac{1-\rho_K^2(s)}{\rho_K(s)}(\ln\frac{1+\rho_K(s)}{1-\rho_K(s)} - \ln\frac{1+\frac{\rho_K(s)}{1+2x_1^2/s}}{1-\frac{\rho_K(s)}{1+2x_1^2/s}})$$

$$\tilde{I}_{K^+K^-}^{K^+}(s,x_1) = \frac{s}{\pi}\int_{4m_K^2}^{\infty}\frac{\rho_K(s')M_{00}^{Born\,K^+}(s',x_1)}{s'(s'-s-i\epsilon)}$$

New data description

We get rid of the a_0' and the kaon formfactor and arrived to the following description ($\chi^2/n.d.f. = 6.9/23$).

Keeping the a_0' leads to fantastic $\chi^2/n.d.f. = 1.3/17$.


60
50
40
30
20
10
0
0.8
1.0
1.2
1.4
1.6
1.8

The dependence on $k_2^2 = -Q^2$

$$M_{1-1}(\gamma\gamma \to a_2(1320) \to \pi^0\eta)(s,\theta,\phi,Q) = A(s)\sin^2\theta_\pi e^{2i\phi_\pi}\frac{1+\frac{Q^2}{s}}{1+\frac{Q^2}{m_\rho^2}}$$

$$M_{10}(\gamma\gamma \to a_2(1320) \to \pi^0\eta)(s,\theta,\phi,Q) = -A(s)\sin\theta_\pi\cos\theta_\pi e^{i\phi_\pi}\sqrt{\frac{2Q^2}{s}}\frac{1+\frac{Q^2}{s}}{1+\frac{Q^2}{m_\rho^2}}$$

$$M_{11}(\gamma\gamma \to a_2(1320) \to \pi^0\eta)(s,\theta,\phi,Q) = -A(s)\frac{Q^2}{s}(\cos^2\theta_\pi - \frac{1}{3})\frac{1+\frac{Q^2}{s}}{1+\frac{Q^2}{m_\rho^2}}$$

$$A(s) = 20\pi\sqrt{\frac{6s\Gamma_{a_2\to\gamma\gamma}(s)\Gamma_{a_2\to\eta\pi^0}(s)}{\rho_{\eta\pi}(s)}}$$

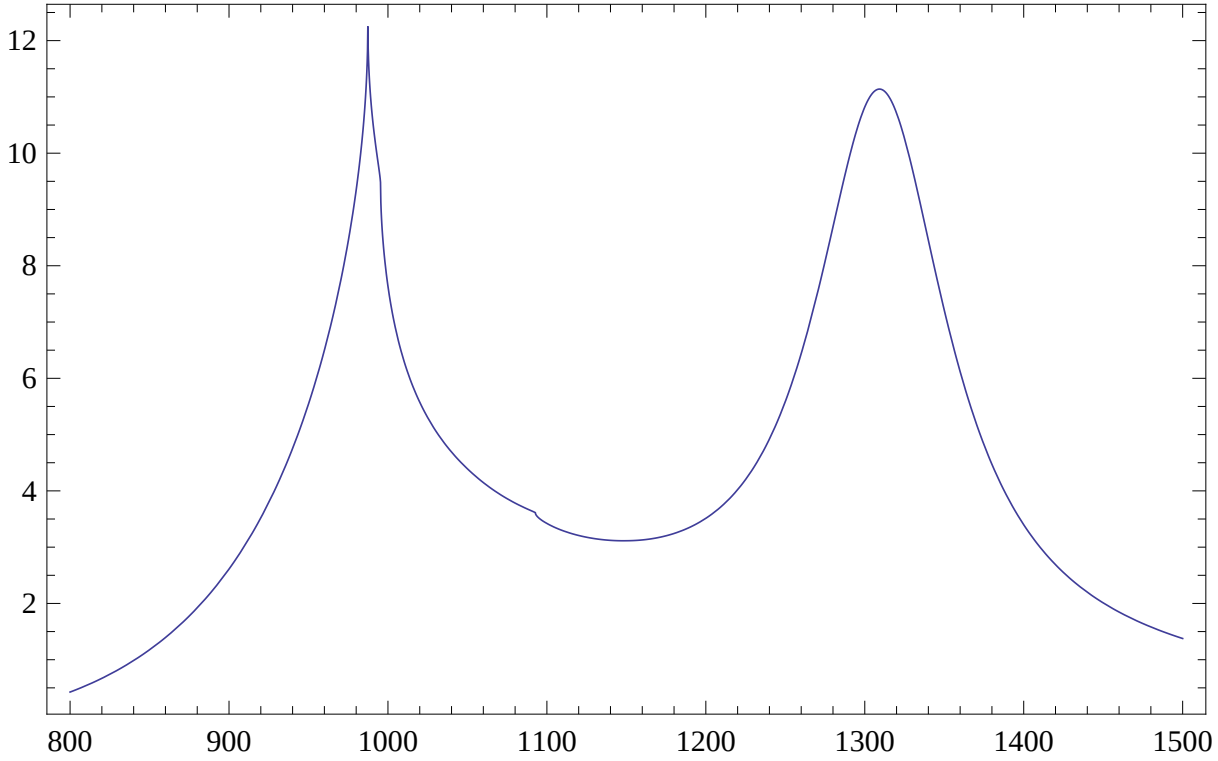
$$\widetilde{I}^{K^+}_{K^+K^-}(s,Q) = -8\alpha(1 + \frac{Q^2}{s+Q^2}(\rho_K(s)(\ln\frac{1+\rho_K(s)}{1-\rho_K(s)} - i\pi) -$$

$$-\rho_K(-Q^2)\ln\frac{1+\rho_K(-Q^2)}{\rho_K(-Q^2)-1} +$$

$$\frac{m^2_{K^+}}{Q^2}(-\ln^2\frac{1+\rho_K(-Q^2)}{\rho_K(-Q^2)-1} + (\ln\frac{1+\rho_K(s)}{1-\rho_K(s)} - i\pi)^2)))$$

At $Q \to \infty \qquad \widetilde{I}^{K^+}_{K^+K^-}(s,Q) \to 8\alpha\ln\frac{Q^2}{m^2_K}$**.**

So tensor contribution will be dominant at large Q^2**.**


12
10
8
6
4
2
800
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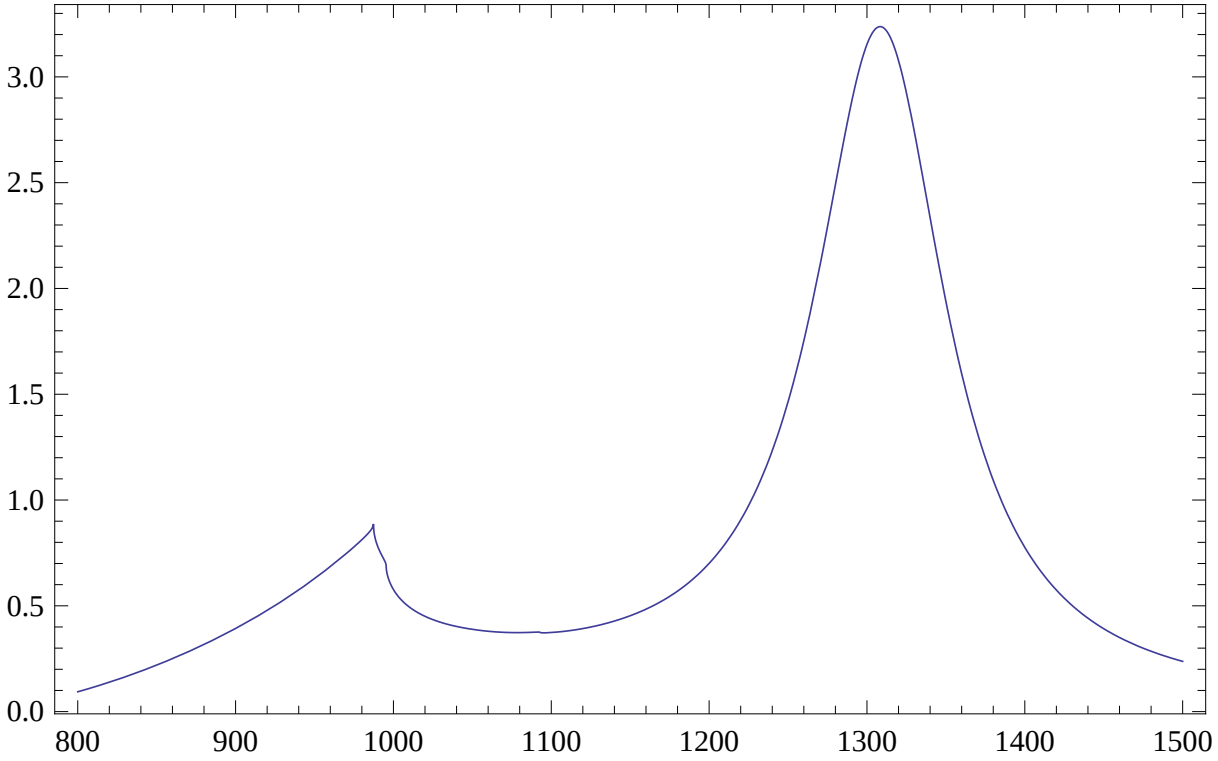
1000
1100
1200
1300
1400
1500


3.0
2.5
2.0
1.5
1.0
0.5
0.0
800
900
1000
1100
1200
1300
1400
1500

Summary

1. The Belle data on $\gamma\gamma \to \eta\pi^0$ have been reanalyzed. The description without a_0' and the kaon formfactor $G_{K^+}(t,u)$ is obtained.
2. The Q^2 dependency has been predicted for the near future experiments.