Two-photon exchange effects in $ep \rightarrow eN\pi$ at $\Delta(1232)$ peak

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Outline

1. Motivation

2. Introduction

3. TPE in ep->eNπ at $\Delta(1232)$ peak

4. Numerical results and summary

Motivation

1. It has been known that the two photon exchange effects give large corrections to the ratio of proton's EM form factors $\mu_p R = \mu_p G_E(Q^2)/G_M(Q^2)$ by Rosenbluth method (extract the ratio from the un-polarized ep scattering data).

A natural question is how about TPE corrections in the other processes when we aim at the precise measurement of hadrons' electromagnetic structure?

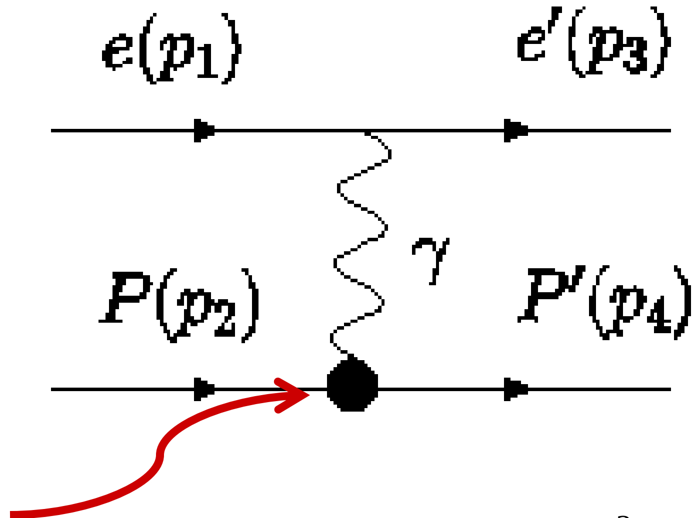
Motivation

2. Δ(1232) is the first excitation of the nucleon, the precise extraction of its deform is an interesting question (is Δ spherical? Namely, does it have a D-state?).

The precise measurement of the cross sections of electromagnetic production of pion on Δ(1232) peak, calls for the corresponding precise theoretical estimation on the radiative corrections. The TPE contribution at high Q^2 was first studied in 2006 by using the GPDs methods. This also attracts us to study this question at small Q^2.

Introduction: one photon exchange in ep->ep

In ep->ep scattering, the one photon exchange approximation (OPE) is used to extracted the EM form factors of proton before 2003.

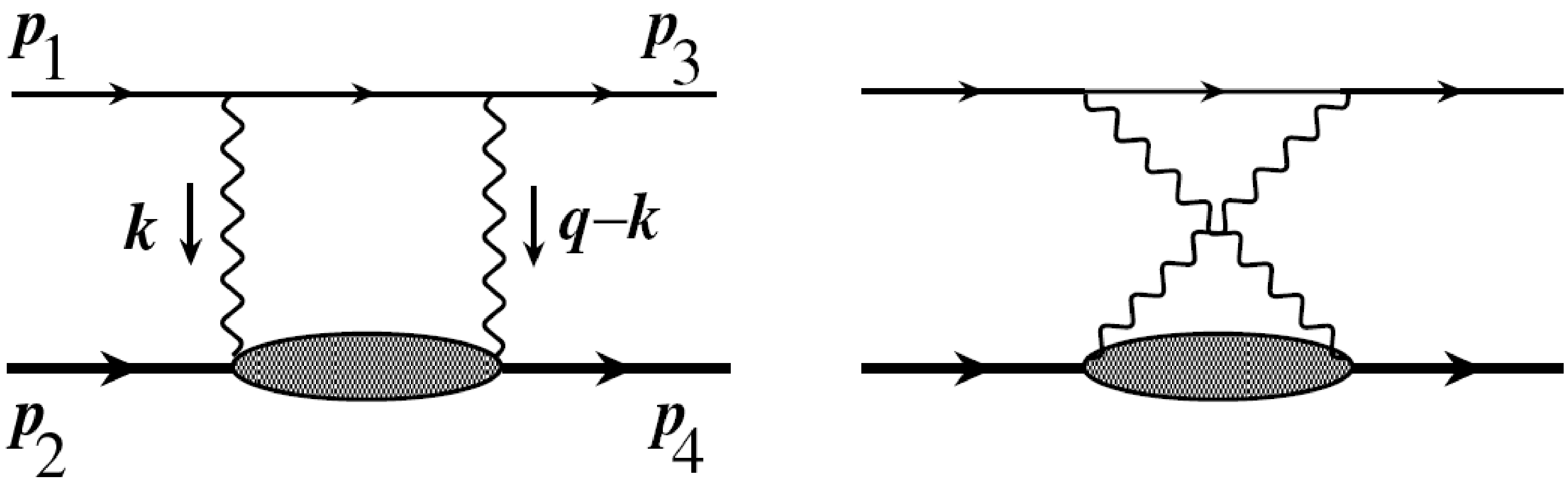


$$\Gamma^{\mu}_{\gamma N\to N}(q) = ie[F_1(q^2)\gamma_{\mu} + \frac{F_2(q^2)}{m_N}\sigma_{\mu\nu}q^{\nu}]$$

EM radiative corrections are also considered and ***soft photon approximation*** is used in TPE before 2003.

Introduction: TPE in unpolarized ep->ep

In 2003, it is found that the TPE contribution (with finite k) gives large corrections to the extracted $\mu_p R$ from the unpolarized ep scattering data [1].

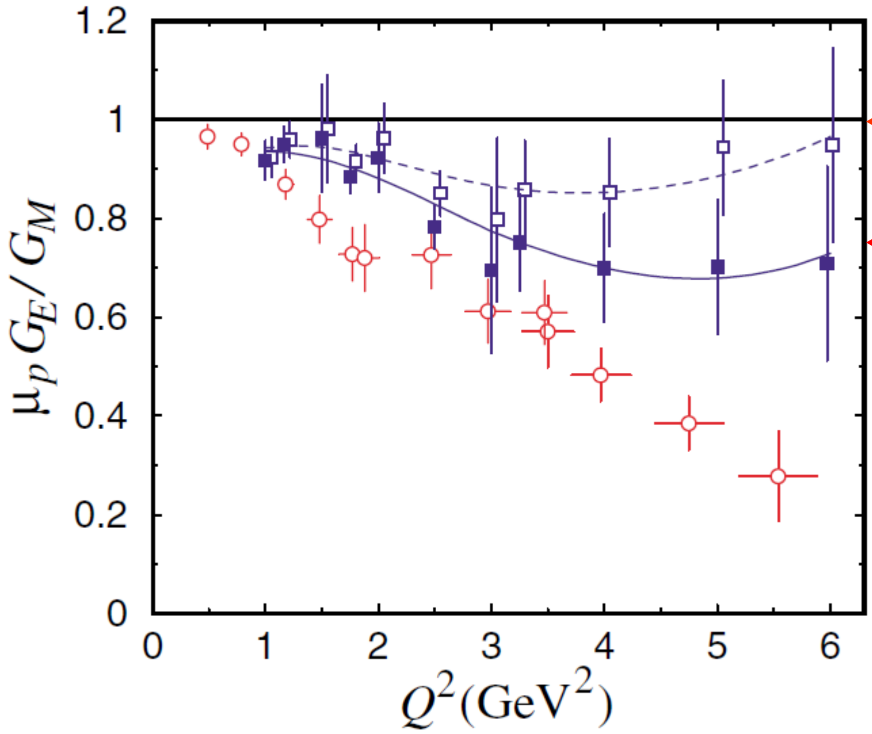


TEP exchange contribution with finite k

[1]P.G. Blunden, W. Melnitchouk and J. A. Tjon, PRL91 (2003) 142304

Introduction: TPE in unpolarized ep->ep

numerical results for the TPE corrections to $\mu_p R$ [1]



hollow:OPE

solid :OPE+TPE

[1]P.G. Blunden, W. Melnitchouk and J. A. Tjon, PRL91 (2003) 142304

Introduction: TPE in ep->ep

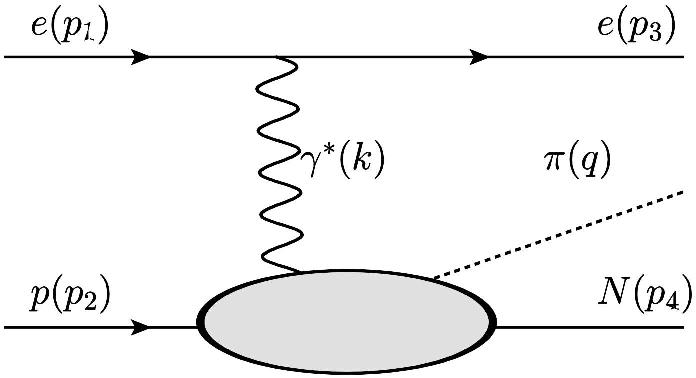
many model dependent methods are used to estimate the TPE effects in the literature.

(1) hadronic model:	J.A.Tjon	etc
(2) GPDs:	M.Vanderhaeghen	etc
(3) dispersion relation:	C. J. Horowitz	etc
(4) pQCD:	M.Vanderhaeghen	etc
(5) SCEF:	M.Vanderhaeghen	etc

PRL91 (2003) 142304; PRL93(2004) 12230;
PRC 78 (2008) 025208; PRL103 (2009) 092004.

γ*N->Δ FFs from the ep->eNπ

In OPE approximation, the amplitude for ep->eNπ can be written in a general from



$$iM_{ep\to eN\pi} = \bar{u}(p_3)(-ie\gamma_\mu)u(p_1)\frac{-i}{k^2}(iM^\mu_{\gamma^* p\to N\pi})$$

$$iM^\mu_{\gamma^* p\to N\pi} = \sum_{i=1}^{6}\bar{u}(p_4)A_i M_i^\mu u(p_2)$$

where M_i are 6 special Dirac matrix structures[1], and the invariant amplitudes A_i can be expressed by the multipoles which are only dependent on the W and Q^2

$$Q^2 = -(p_1 - p_3)^2, W^2 = (q + p_4)^2$$

[1]B. Pasquini, D. Drechsel, and L. Tiator, Eur. Phys. J. A 34, 387–403 (2007)

ep->eNπ in OPE

in detail, the invariant amplitudes A_i can be expressed as functions of the CGLN amplitudes which can be expanded on the multipoles

$$\mathcal{F}_1 = \sum_{l=0}^{\infty} [(l M_{l+} + E_{l+}) P_{l+1}'(x) + ((l+1) M_{l-} + E_{l-}) P_{l-1}'(x)],$$

where the multipoles M_l, E_l and S_l are only dependent on Q^2. And at the Δ(1232) peak $W=M_\Delta$, the E_1^+, M_1^+, S_1^+ play the most important roles, which reflect the electromagnetic form factors of γ*N->Δ.

ep->eNπ in OPE

Models (under OPE approximation) are usually used to extract the E_{1}^{+}, M_{1}^{+}, S_{1}^{+} multipoles from the experimental data [1], for example :

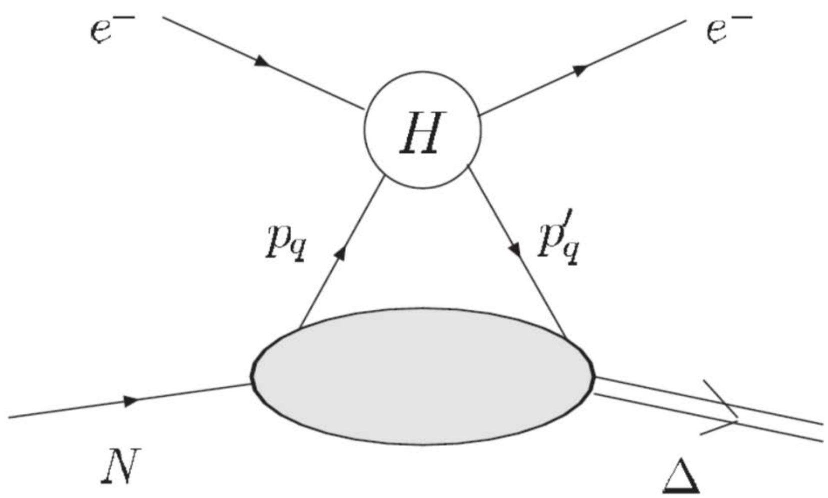
MAID2007 ans SAID.

In these models, the background are all considered at Δ(1232) peak. The including of the background is also important to extract the multipoles.

[1] http://portal.kph.uni-mainz.de/MAID// http://gwdac.phys.gwu.edu/

TPE in the ep->eNπ

The TPE effect in the ep->eNπ at larger momentum transfer Q^2 was first studied in 2006 by using the GPDs methods [1], where only the Δ(1232) peak contribution is considered in both the TPE and OPE.

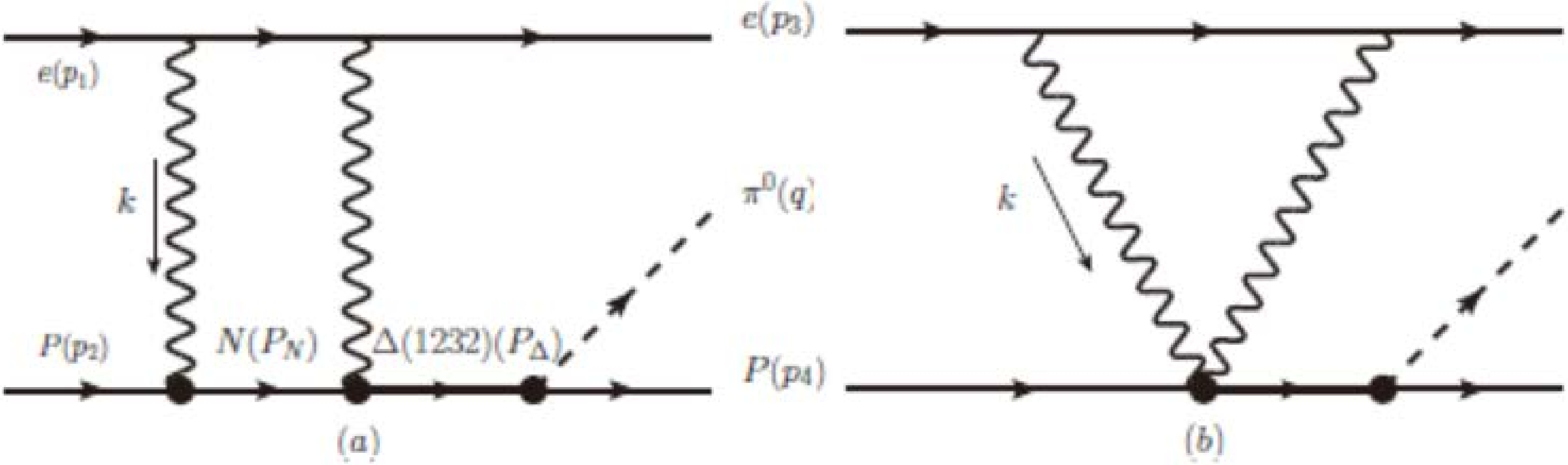


ep->eΔ->eNπ by GPDs

[1]Vladimir Pascalutsa,Carl E. Carlson, and Marc Vanderhaeghen, PRL96 (2006) 012301

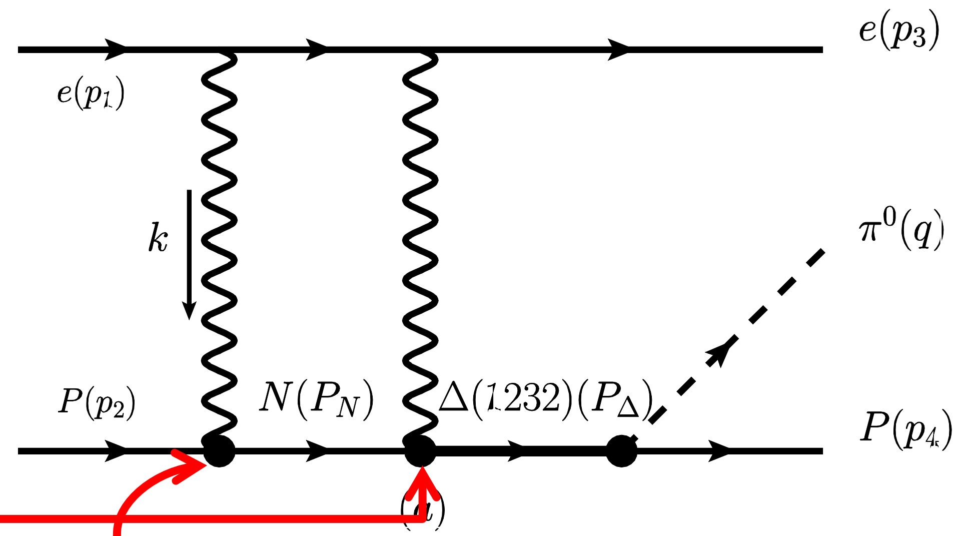
TPE in ep->eNπ

In this talk, we report the TPE effect at low momentum transfer base on a simple hadronic model. We considered the following contributions in the electromagnetic production of pion at Δ(1232) peak.



ep->eΔ->eNπ TPE in hadronic model

TPE in ep->eNπ: the detail



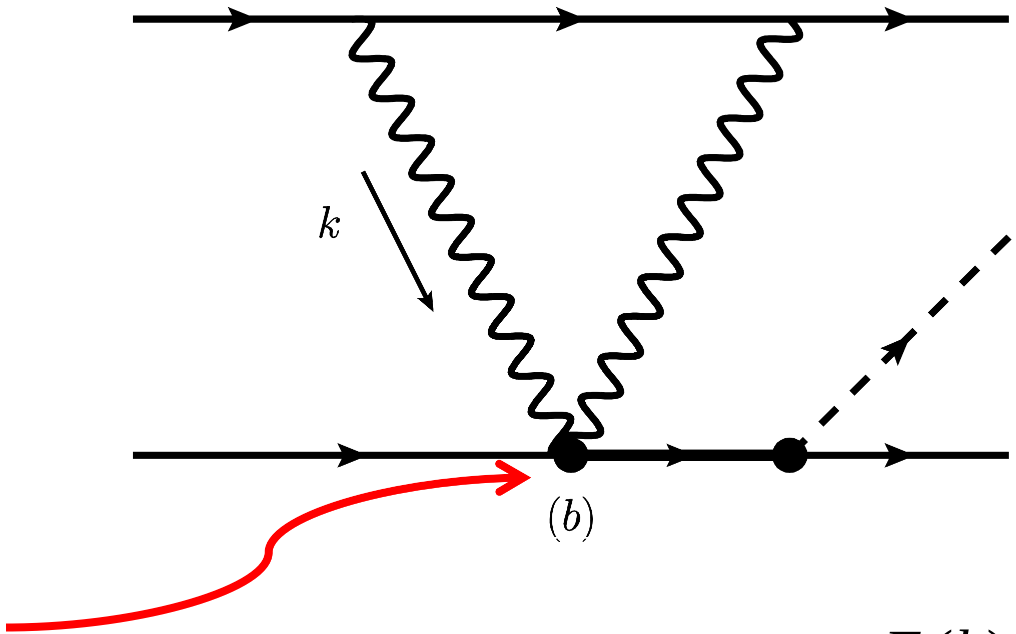
$$\Gamma^{\mu}_{\gamma N\to N}(q) = ie[F_1(q^2)\gamma_\mu + \frac{F_2(q^2)}{m_N}\sigma_{\mu\nu}q^\nu]$$

$$\Gamma^{\nu\beta}_{\gamma N\to\Delta}(p,q) = -i\sqrt{\frac{2}{3}}\frac{e}{2M_\Delta^2}\gamma_5\{g_1(q^2)[g^{\nu\beta}\not{q}\,\not{p} - p^\nu\not{q}\gamma^\beta - \gamma^\beta\gamma^\nu p\cdot q + \not{p}\gamma^\nu q^\beta]$$

$$+g_2(q^2)[p^\nu q^\beta - g^{\nu\beta}p\cdot q] - g_3(q^2)/M_\Delta[q^2(p^\nu\gamma^\beta - g^{\nu\beta}\not{p}) + q^\nu(q^\beta\not{p} - \gamma^\beta p\cdot q)]\}$$

S. Kondratyuk, P. G. Blunden, W. Melnitchouk, J. A. Tjon, PRL 95, 172503 (2005)

TPE in ep->eNπ: the detail



$$\Gamma^{\nu\nu\beta}_{\gamma\gamma N\Delta}(P_\Delta, p_2, k, \bar{k}) = e\Big\{(2p_2+k)^\nu \frac{F_1(k)}{(p_2+k)^2 - M_N^2}\Gamma^{\mu\beta}_{\gamma N\to\Delta}(P_\Delta, \bar{k})$$

$$+(2p_2+\bar{k})^\nu \frac{F_1(\bar{k})}{(p_\Delta-k)^2 - M_N^2}\Gamma^{\nu\beta}_{\gamma N\to\Delta}(P_\Delta, k)\Big\}$$

S. Kondratyuk , P.G. Blunden, Nucl.Phys. A778,44(2006).

unpolarized cross sections for ep->eNπ

The unpolarized cross section in OPE case and OPE+TPE case both can be written as

$$\frac{d\sigma^{1\gamma,2\gamma}}{d\Omega_\pi} = \sigma_0^{1\gamma,2\gamma} + \sqrt{2\varepsilon(1+\varepsilon)}\sigma_{LT}^{1\gamma,2\gamma}\cos\phi + \varepsilon\sigma_{TT}^{1\gamma,2\gamma}\cos 2\phi$$

where ε is the transverse polarization of the virtual photon, ϕ is the angle between the electron scattering plane and the reaction plane, θ is the angle between the momentums of pion and nucleon.

From the ϕ dependence of the cs, the $\sigma_{0,LT,TT}$ can be seperated.

Vladimir Pascalutsa,Carl E. Carlson, and Marc Vanderhaeghen, PRL96 (2006) 012301

unpolarized cross sections for ep->eNπ

In OPE case: both $\sigma_{LT,TT}$ are ε independent, and θ dependent

In OPE+TPE case: both $\sigma_{LT,TT}$ are ε,θ dependent

which means the TPE corrections to the cross sections are ε dependent.

from cross sections to multipole

In this work, the TPE corrections to the cross sections are calculated directly for the TPE diagrams in the hadronic model, and we use MAID2007 and SAID to estimate the OPE amplitude.

To get the corresponding corrections to the multipoles, we fitting the cross sections using the formula under OPE approximation.

from cross sections to multipole

We use the cross sections from the models to simulate the experimental data, and then get the "physical" cross sections after subtracting the TPE correction

$$\sigma_{0,LT,TT}^{Ex} \approx \sigma_{0,LT,TT}^{model} = \sigma_{0,LT,TT}(Z_{l^{\pm}}^{model})$$

$$\sigma_{0,LT,TT}^{1\gamma} = \sigma_{0,LT,TT}^{Ex} - \sigma_{0,LT,TT}^{2\gamma}$$

Since we only consider the TPE at the Δ(1232) peak, which will only give contributions to the E_{1+}, M_{1+}, L_{1+}. then we can assume

$$\sigma_{0,LT,TT}^{1\gamma} = \sigma_{0.LT,TT}(Z_{l^{\pm}}^{model}, E_{1^{+}}^{1\gamma}, M_{1^{+}}^{1\gamma}, S_{1^{+}}^{1\gamma})$$

from cross sections to multipole

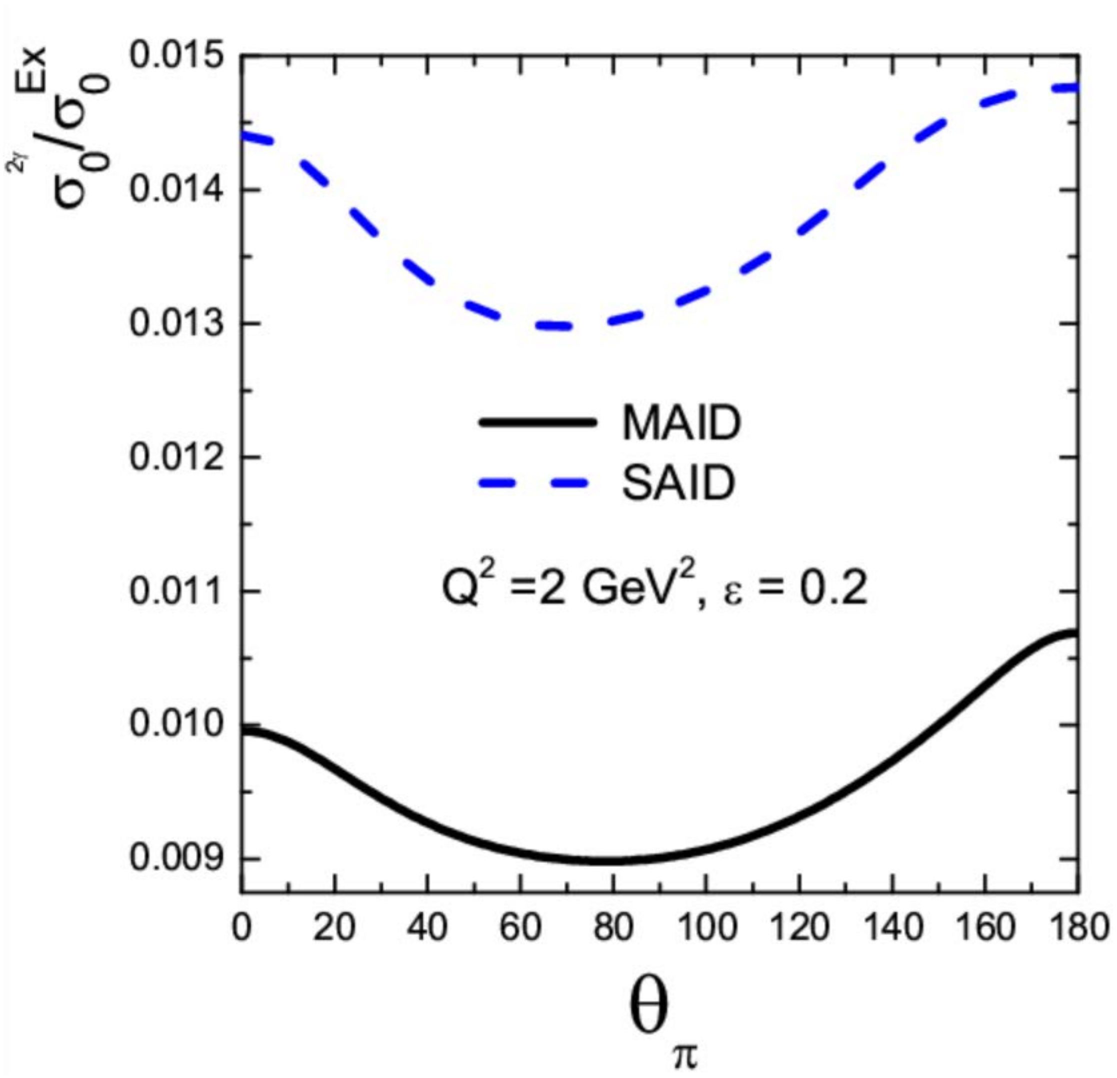
In practice, we use the following fitting to get the corresponding multipoles from $\sigma_{0,LT,TT}^{Ex}$ and $\sigma_{0,LT,TT}^{1\gamma}$

$$\chi^2 = \sum_{\theta=1}^{179} (\sigma_i^{Ex} - \sigma_i(|E_{1^+}^{Ex}|, |M_{1^+}^{Ex}|, |S_{1^+}^{Ex}|))$$

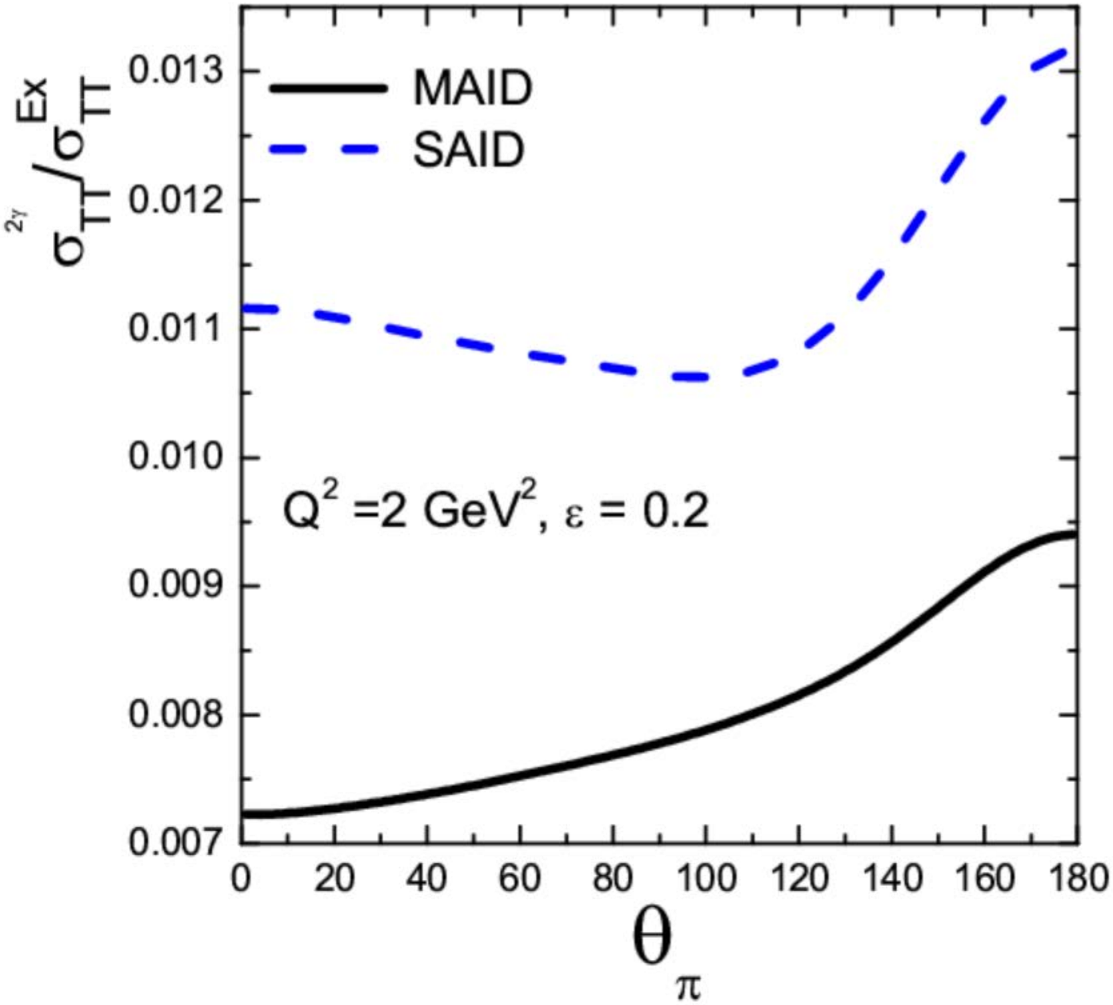
$$\chi^2 = \sum_{\theta=1}^{179} (\sigma_i^{1\gamma} - \sigma_i(|E_{1^+}^{1\gamma}|, |M_{1^+}^{1\gamma}|, |S_{1^+}^{1\gamma}|))$$

Here the contributions from the background have been included in the OPE, and the M_{1+} dominance approximation is not used to extract the multipoles.

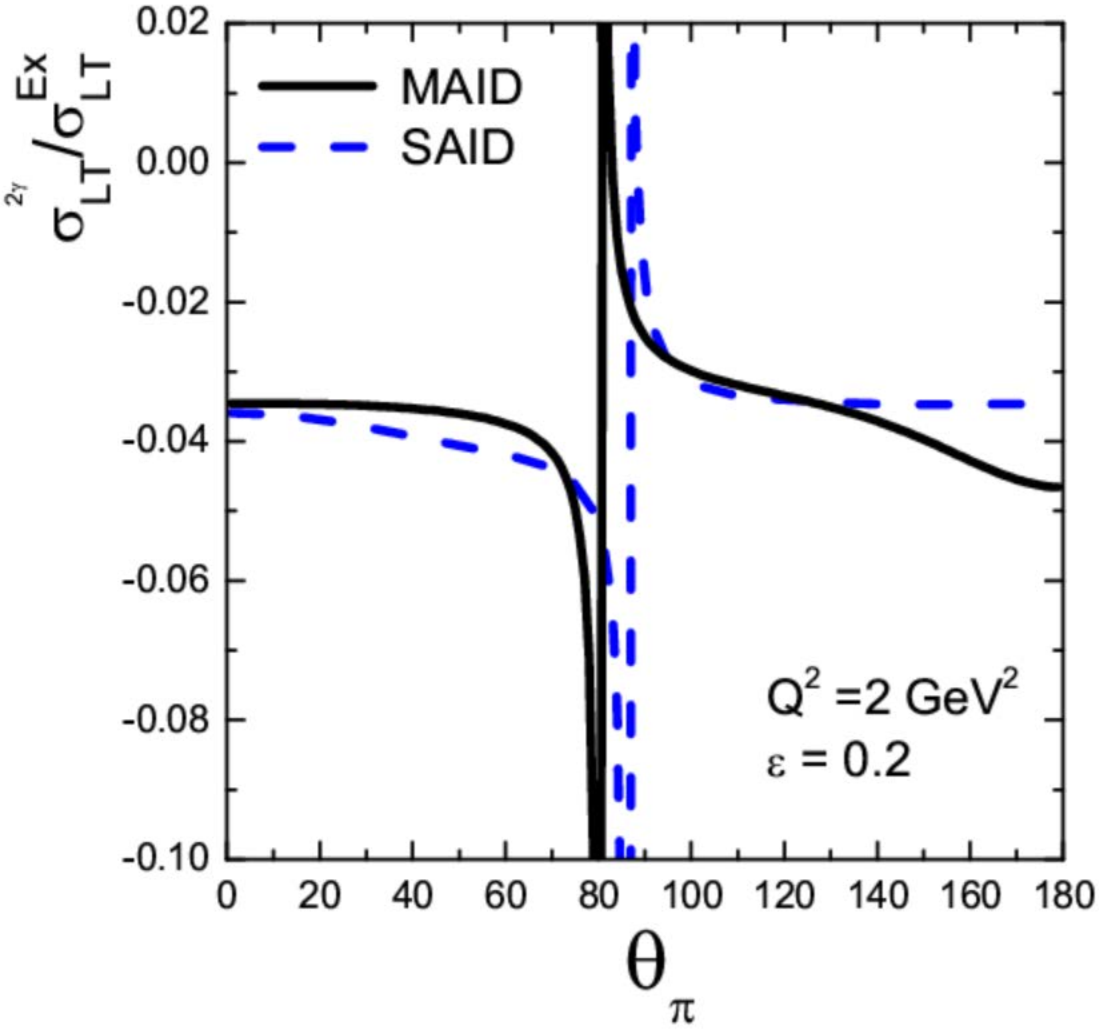
TPE correction to the cross sections



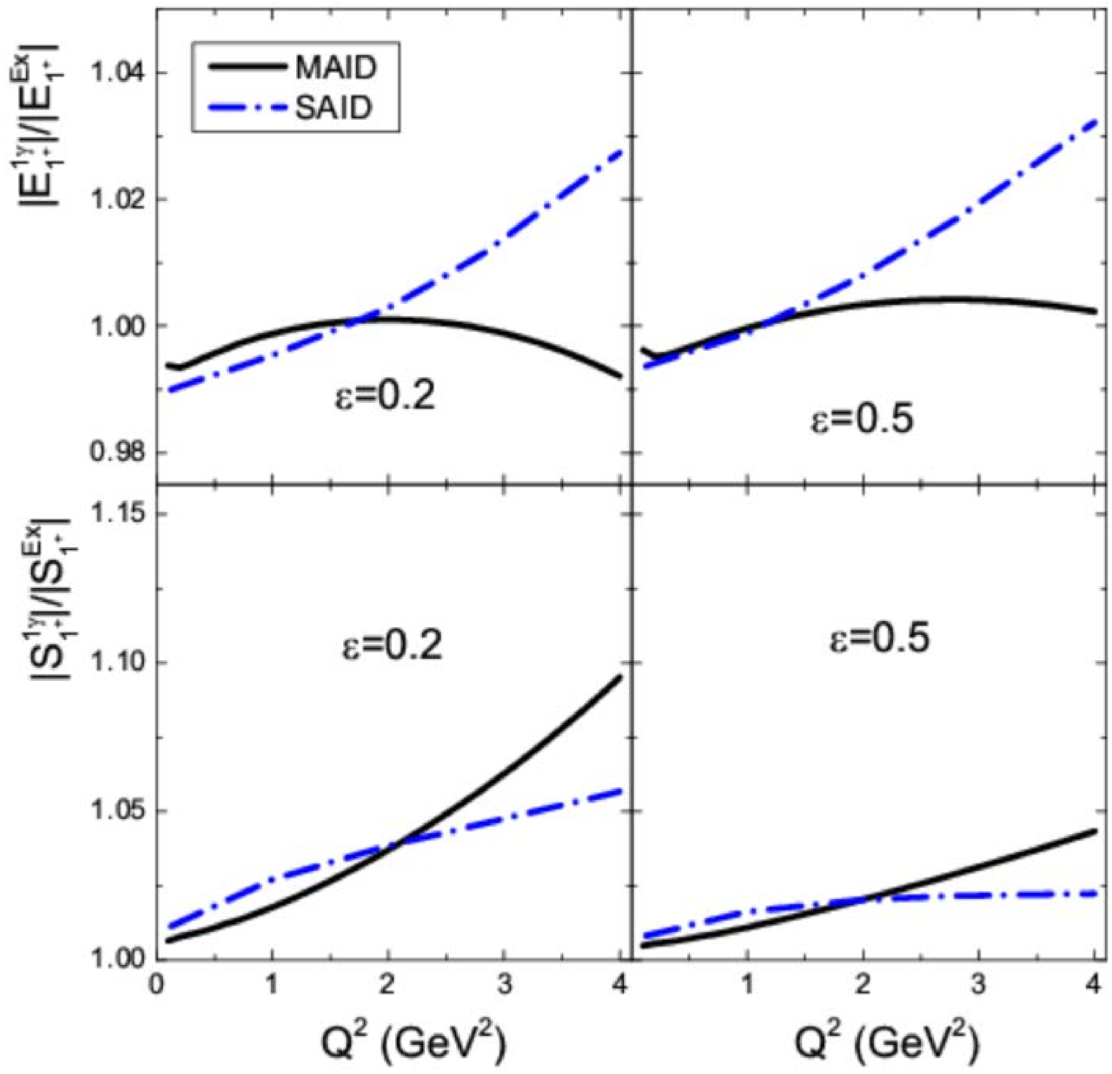
TPE correction to the cross sections



TPE correction to the cross sections

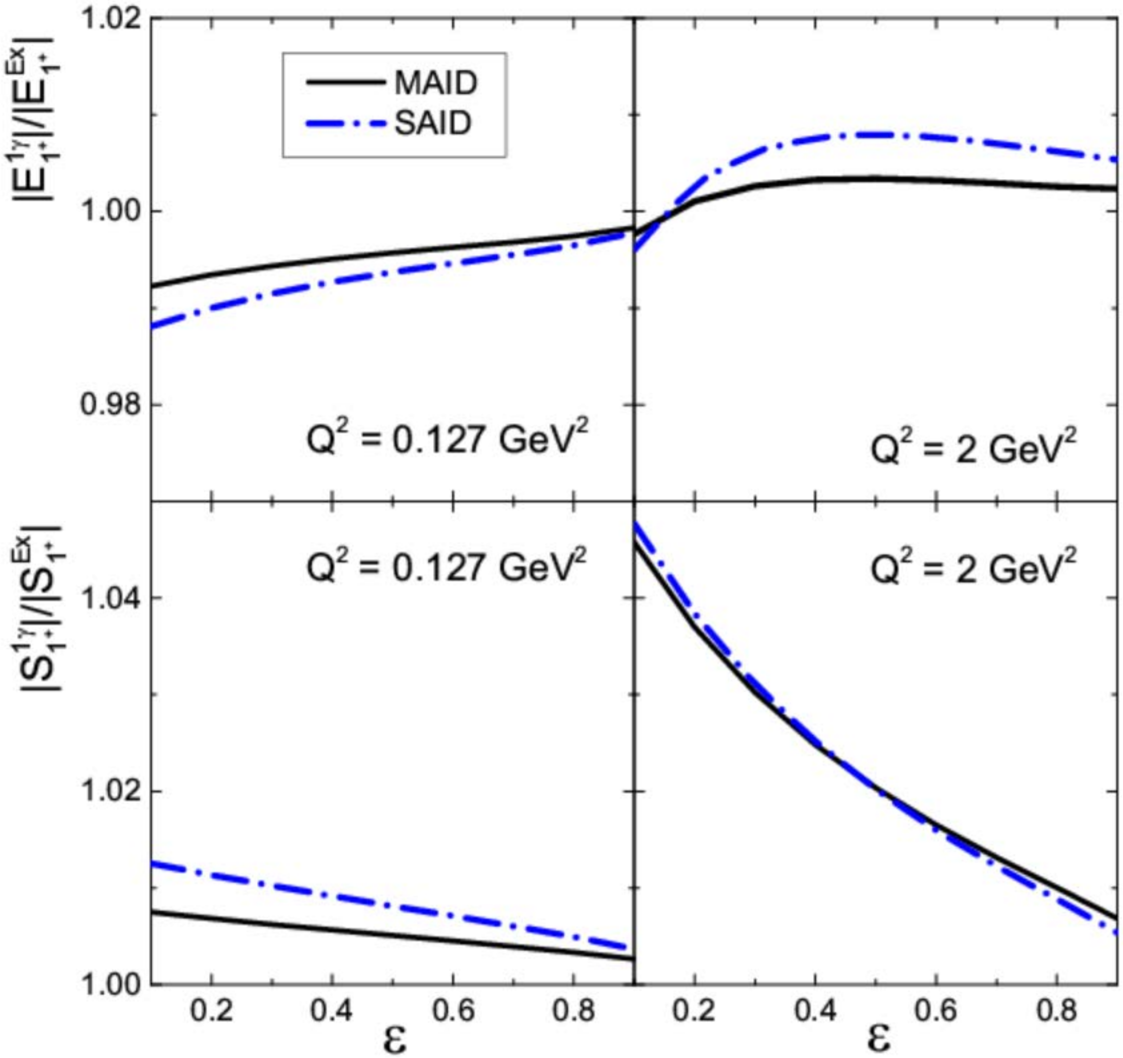


TPE correction to the multipoles

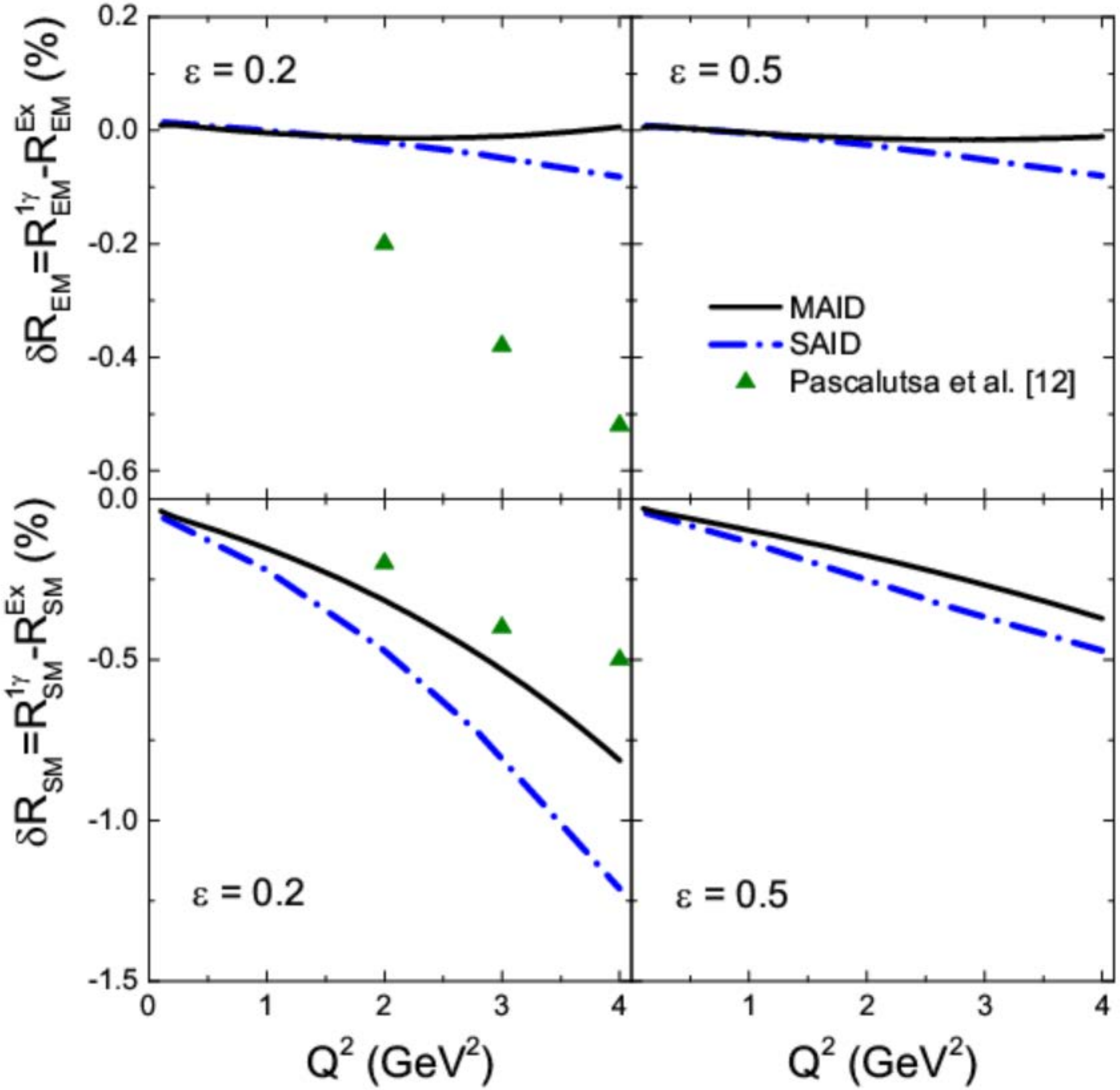


The TPE corrections to M_{1+} are as small as 0.1% and are not showed.

TEP correction to the multipoles



TPE corrections to the $R_{EM,SM}$



$$R_{EM} \equiv \frac{\mathrm{Im}[E_{1^+}^{(3/2)}]}{\mathrm{Im}[M_{1^+}^{(3/2)}]}$$

$$R_{SM} \equiv \frac{\mathrm{Im}[S_{1^+}^{(3/2)}]}{\mathrm{Im}[M_{1^+}^{(3/2)}]}$$

[12]Vladimir Pascalutsa,Carl E. Carlson, and Marc Vanderhaeghen, PRL96 (2006) 012301

Summary and conclusion

We calculate the TPE contributions in ep->eNπ at Δ(1232) peak with Q^2<4GeV^2, and find

1. the TPE corrections to the mulitpoles are from -1% to 6% in, and decrease when ε increase.

2. the model dependence of theTPE corrections is moderate especially when Q^2>2GeV^2.

3. our results are very different with those given by GPDs at Q^2 =2-4GeV^2, δR_{EM} are much smaller and δR_{SM} are much larger

Thanks!

Appendix: experimental data

Table 2. Extracted values for σ_0, σ_{LT}, and σ_{TT} at $Q^2 = 0.127\ (\mathrm{GeV}/c)^2$. The uncertainties correspond to the statistical and the systematic uncertainties, respectively.

W (MeV)	θ^*_{pq} °	σ	σ ($\mu b/sr$)
1232	28	σ_0	$15.51 \pm 0.20 \pm 0.65$
1232	28	σ_{LT}	$1.62 \pm 0.13 \pm 0.16$
1232	28	σ_{TT}	$-3.98 \pm 0.16 \pm 0.32$

Eur. Phys. J. A 49(2013) 136

Table 1. Extracted values for $\sigma_0, \sigma_{LT}, \sigma_{TT}$, and $\sigma_{LT'}$ at $Q^2 = 0.20\ (\mathrm{GeV}/c)^2$. The uncertainties correspond to the statistical and the systematic uncertainties, respectively.

W (MeV)	θ^*_{pq} °	σ	σ ($\mu b/sr$)
1205	34	σ_0	$18.75 \pm 0.21 \pm 0.69$
1205	34	σ_{LT}	$1.69 \pm 0.05 \pm 0.13$
1205	34	σ_{TT}	$-4.62 \pm 0.15 \pm 0.30$
1205	34	$\sigma_{LT'}$	$1.94 \pm 0.21 \pm 0.34$
1221	34	σ_0	$18.86 \pm 0.21 \pm 0.68$
1221	34	σ_{LT}	$1.94 \pm 0.06 \pm 0.12$
1221	34	σ_{TT}	$-5.41 \pm 0.16 \pm 0.32$
1221	34	$\sigma_{LT'}$	$2.10 \pm 0.22 \pm 0.35$
1232	34	σ_0	$17.10 \pm 0.20 \pm 0.68$
1232	34	σ_{LT}	$1.85 \pm 0.06 \pm 0.13$
1232	34	σ_{TT}	$-5.37 \pm 0.16 \pm 0.33$
1232	34	$\sigma_{LT'}$	$1.98 \pm 0.21 \pm 0.34$