Regge approach to backward electromagnetic production of meson with parton contributions

(Daresbury NINA data 1977 / JLab Fπ-2 data 2019)

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Outline

- Physics Motivation and Goal (5)
  - GPD/TDA for quark structures in hadron reactions at high s and Q^2
  - Set up a Regge + parton model to test GPD/TDA in such extreme kinematic regions (Quick and easy plot for u-ch. process in experiments)
- Photoproduction (NINA/Daresbury) (10)
  - DCS data; hadron + parton at backward angles
  - u-ch. Nucleon Reggeon at backward angles
  - Meson-baryon form factor from GPDs & TDA

    ω, ρ^0 & ϕ photoproductions

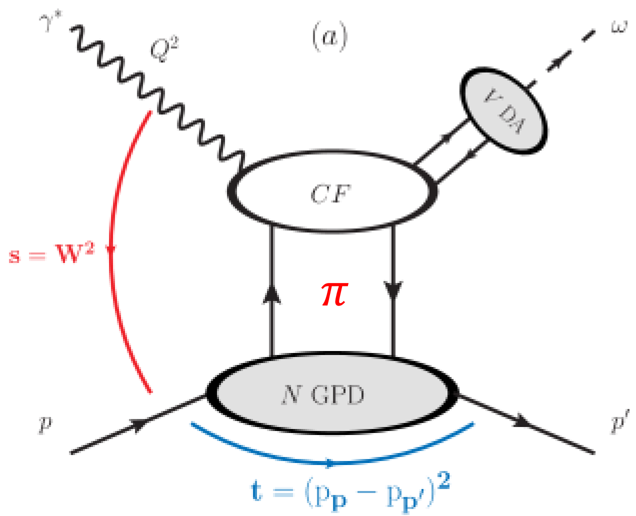
    πΔ photoproduction
- Electroproduction (CLAS-6 GeV & Fpi-2/JLab) (10)

    ω electroproduction

    π electroproduction
  - Extension to electroproduction with dipole form factors for $\gamma^* NN$
  - GPDs & TDA for πNN and ωNN vertex form factors
- Summary (5)

1. Electromagnetic production of ω

FORWARD



πNN form factor

Nucleon GPD: VGG model

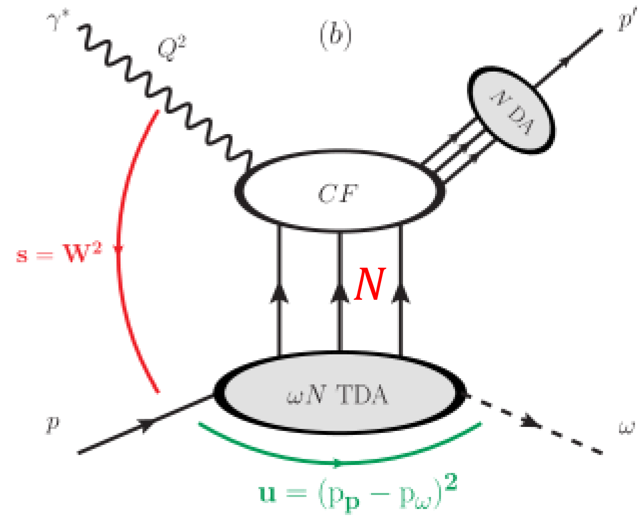
Phys. Rev. D 56 (1997) 2982

$$\left\langle N \middle| \bar{q}(r^-)\gamma^+ W[r^-,0] q(0) \middle| N \right\rangle$$

$$\sim \left\{ H^q, E^q, \tilde{H}^q, \tilde{E}^q \right\}(x,\xi,t) \quad \rightarrow 8$$

$$\sim \left\{ F_1, F_2, G_A, G_P \right\}(t)$$

BACKWARD



ωNN form factor

Nucleon TDA: PSS model

Phys. Rev. D 91, 094006 (2015)

$$\left\langle \omega \middle| \varepsilon_{c_1 c_2 c_3} u_\rho^{c_1} u_\tau^{c_2} d_\chi^{c_3} \middle| N \right\rangle$$

$$\sim H_{s,f}^{\omega N} = \left\{ V_{1,2}^{\omega N}, A_{1,2}^{\omega N}, T_{1,2,3}^{\omega N} \right\} \quad \rightarrow 24$$

$$\sim H_{s,f}^{\omega N}(x_i,\xi,\Delta^2) = H^{\omega N}(x_i/\xi) \times K(\xi,u)$$

2.Hadron model for high energy & at small u (large t)

QCD Factorization btwn hard and soft amplitudes

$$s \gg M^2,\ t \to 0,\ Q^2 \sim 10\ GeV^2$$

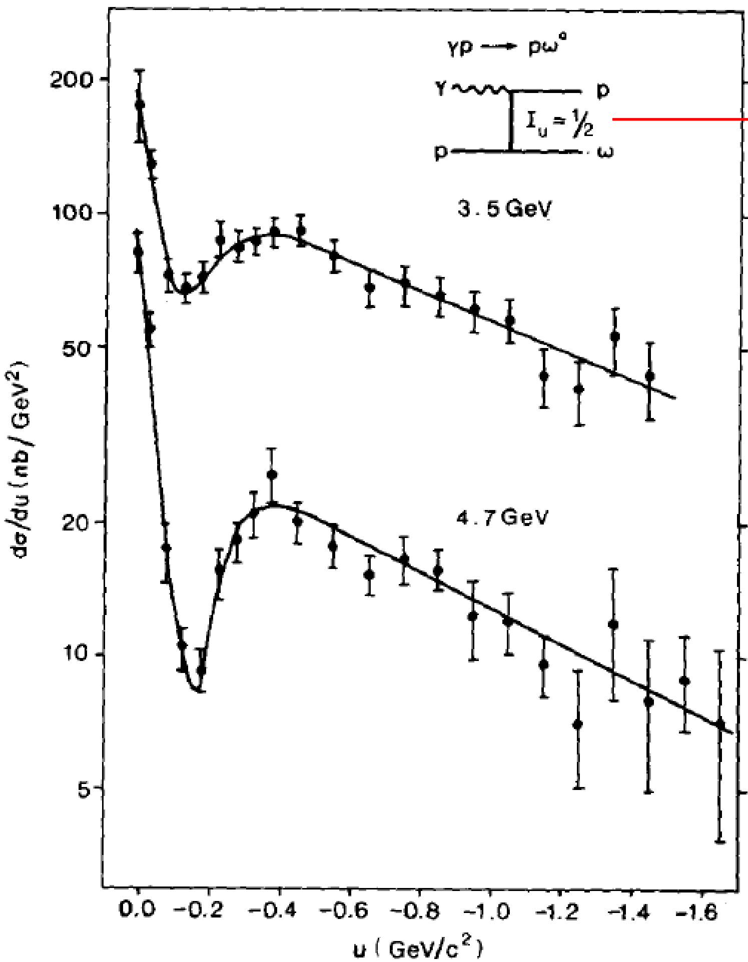
- VGL model ~ good for σ_L, but σ_T smaller than data
- VGG model ~ electroproduction σ_L from GPD
- PSS model ~ Backward process from TDA
- BK model for backward ω photoproduction data of NINA, Daresbury
- Simulate PDF via hadron form factors in the Regge model

3. NINA/Daresbury data on ω Photoproduction

R. W. Clifft *et al.*, Phys. Lett. B **72**, 144 (1977)

■ AT BACKWARD ANGLES

NINA data for $-1.8 < u < 0.02$ GeV^2 at E_γ =3.5, 4.7 GeV (Daresbury Lab. by Clifft 1977)



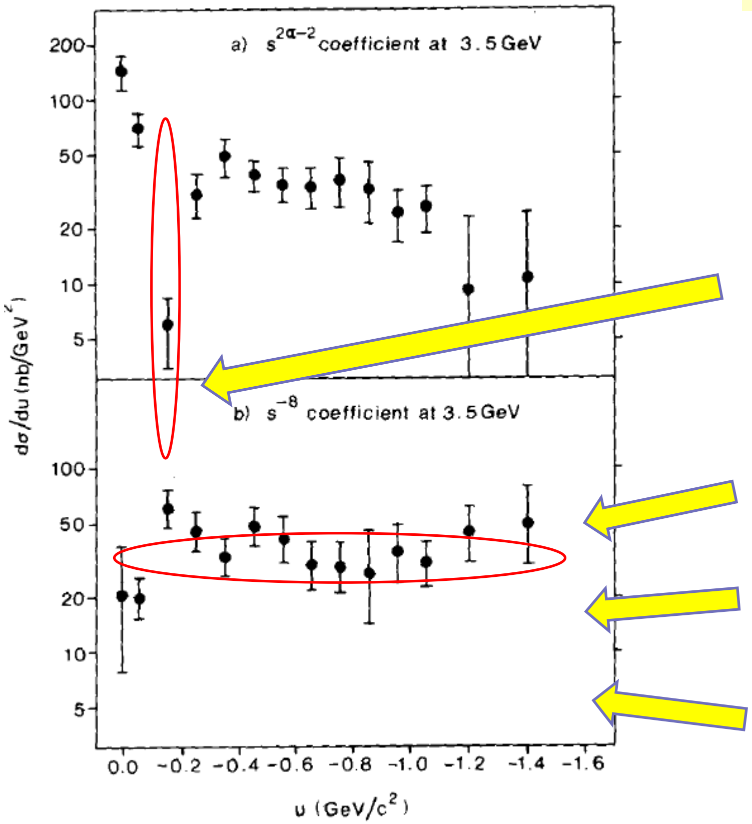
Isoscalar channel

▶ Exp. Observations:

- Only N_α trajectory of u-ch. nucleon with a deep dip at $u = -0.15$ GeV^2, but the depth of a dip weakened by a fraction of $1/3$ at $E_\gamma = 3.5$ GeV
- Needs a mechanism to fill in the dip

▶ Issue of parton contribution in addition to the dip of N_α trajectory in NINA data

$$\frac{d\sigma}{du} = \left| A(u) s^{\alpha(u)-1} + B e^{i\phi(u)} s^{-4} \right|^2$$



- $A \sim N_\alpha$ trajectory of u-ch. nucleon with a deep dip at $u = -0.15$ GeV^2
- $B \sim$ isotropic and independent of u
- Parton contributions with s^8 scaling
- $\phi \sim 90°$ incoherence of A and B

1. Reggeization of nucleon exchange in the u-ch

- Gauge invariant Born terms

Gauge invariance needs s-ch. Proton pole

Direct   Crossed

$$M_s = -\bar{u}(p')\Gamma_{\omega NN}\frac{\not{p}+\not{k}+M_N}{s-M_N^2}\Gamma_{\gamma NN}u(p),$$

$$M_u = -\bar{u}(p')\Gamma_{\gamma NN}\frac{\not{p}'-\not{k}+M_N}{u-M_N^2}\Gamma_{\omega NN}u(p)$$

$$\Gamma_{\gamma NN} = e\left(e_N\not{\epsilon} - \frac{\kappa_N}{4M_N^2}[\not{\epsilon},\not{k}]\right),$$

$$e_N = 1,\ \kappa_N = 1.79$$

$$\Gamma_{\omega NN} = g_{\omega NN}\left(\not{\eta}^* + \frac{\kappa_\omega}{4M_N^2}[\not{\eta}^*,\not{q}]\right)$$

$$g_{\omega NN} = 15.6,\ \kappa_{\omega NN} = 0$$

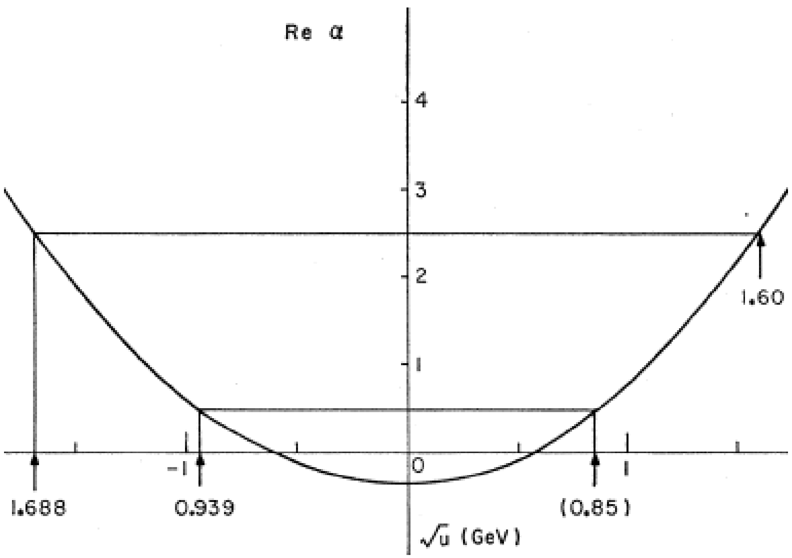
- **Nucleon Regge pole with signature $\tau = +1$**

$$\mathcal{M}_N = (M_s + M_u) \times (u - M_N^2)\, \mathcal{R}^N(s,u)$$

$$\mathcal{R}^N(s,u) = \frac{\pi \alpha'_N}{\Gamma(\alpha_N(u) + 0.5)} \frac{\frac{1}{2}\left(1 + \tau e^{-i\pi(\alpha_N(u) - 0.5)}\right)}{\sin \pi(\alpha_N(u) - 0.5)} \left(\frac{s}{s_0}\right)^{\alpha_N(u) - 0.5}$$

- **N_α trajectory** $\alpha_N^+(\sqrt{u}) = 0.9\,u - 0.365$

- **A dip at $u = -0.15$ GeV^2 from NWS zero,** $1 + e^{-i\pi(\alpha_N(u) - 0.5)} = 0$



2. Parton contribution

- ▶ Nonforward parton distribution as a fill-up mechanism at the dip

- Extended ωNN vertex to include isoscalar FF by similarity to $\gamma^* NN$ vertex

$$g_{\omega NN}\gamma^\mu \left(\frac{s}{s_0}\right)^{\alpha(u)-0.5} \rightarrow g_{\omega NN}\gamma^\mu \left(\frac{s}{s_0}\right)^{\alpha(u)-0.5} + g_{\omega NN}\gamma^\mu \, e^{i\varphi(u)} F_s(u) \left(\frac{s}{s_0}\right)^{\tilde{\alpha}(u)-0.5}$$

$$\mathcal{R}^N \to \mathcal{R}^N + \underline{e^{i\phi(u)} F_s(u) \tilde{\mathcal{R}}^N}$$

- ▶ relative phase between hadron and parton $\quad \phi(u) = (a + bu)\frac{\pi}{180}$
- ▶ nucleon isoscalar form factor $\quad F_s = F_1^p + F_1^n$
- ▶ quark contents $\quad F_1^p = e_u u + e_d d \qquad F_1^n = e_u d + e_d u$

- Regge-like ansatz $R2$ for parton density

M. Guidal, M.V. Polyakov, A. V. Radyushkin, M. Vanderhaeghen, PRD 72, 054013 (2005)

$$q = \int dx \, q_v(x) x^{-(1-x)\alpha'(u-u_0)} \qquad (\alpha' = 0.3)$$

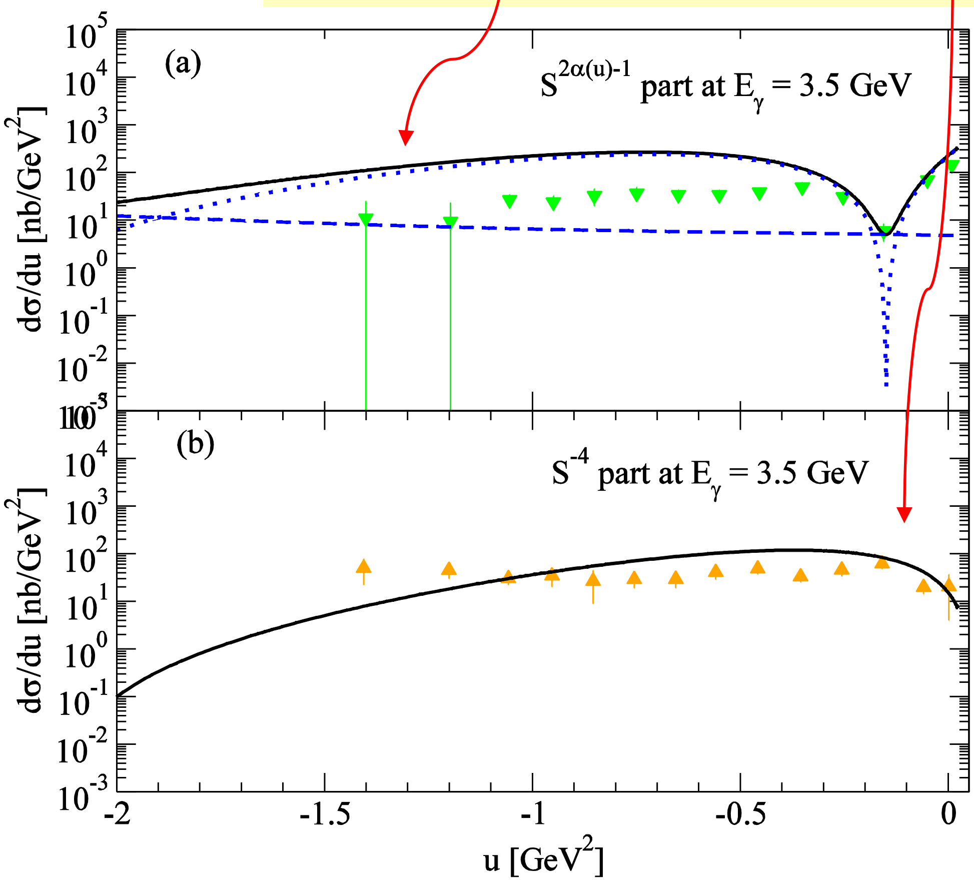
- Unpolarized parton distributions

$$u_v(x) = 0.262 x^{-0.69} (1-x)^{3.5} (1 + 3.8 x^{0.5} + 37.65 x)$$
$$d_v(x) = 0.061 x^{-0.65} (1-x)^{4.03} (1 + 49.05 x^{0.5} + 8.65 x)$$

3. Regge+parton model for simulating NINA data

$$\frac{d\sigma}{du} = \frac{\pi}{kq}\left| (M_s+M_u)(u-M_N^2)\left[R^N + e^{i\varphi(u)} F_s(u)\,\tilde{R}^N\right]\right|^2$$

$$= \left| hadron + e^{i\varphi(u)}\, parton \right|^2$$



Nucleon Reggeon+ meson poles

$$\alpha_N(u) = 0.9u - 0.365 \quad \text{(canon. phase)}$$

Parton

- ▶ Change of trajectory in the present of partons

$$\tilde{\alpha}_p(u) = 0.9u - 0.56 \quad \text{(canon. phase)}$$

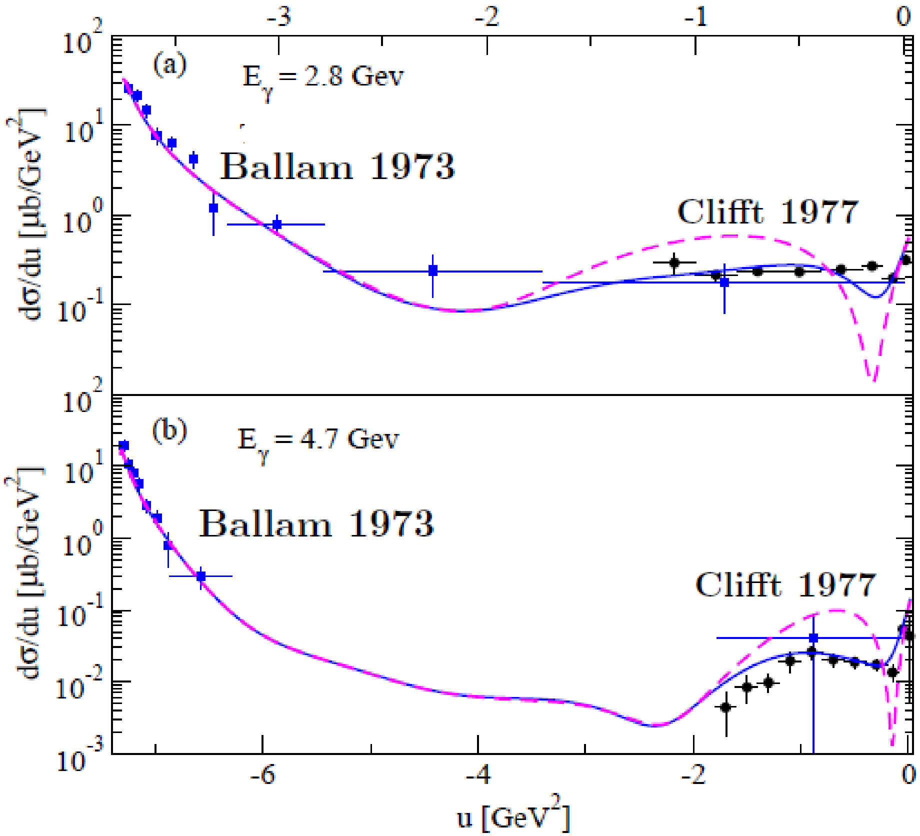
$$\phi(u) = (-65u + 93)\pi/180; \; E_\gamma = 3.5\,\text{GeV}$$

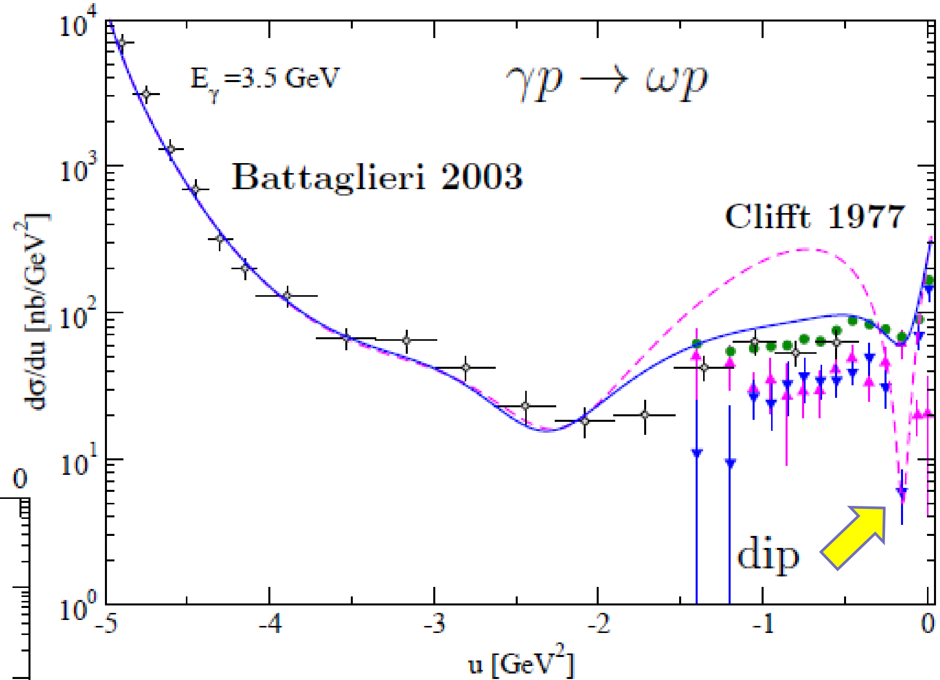
4. Results

- $\dfrac{d\sigma}{du}$ at backward angles

▶ Expected dip at $u = -0.15\ \mathrm{GeV}^2$

by NWSZ of $1 + e^{-i\pi(\alpha_N(u)-1/2)} = 0$





▶ Parameters fit to data

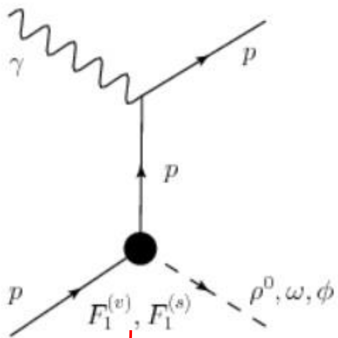
$$\phi(u) = (-95u + 70)\pi/180;\ E_\gamma = 2.8\ \mathrm{GeV}$$

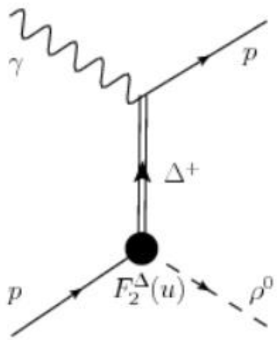
$$\phi(u) = (-35u + 120)\pi/180;\ E_\gamma = 4.7\ \mathrm{GeV}$$

5. Applications

$\omega(782), \rho^0(775)$ & ϕ(1020) photoproductions

* Study GPD contents of nucleon & delta isoscalar/vector FF in u-channel





$F_2^{N\Delta}(u) = F_2^{(v)}(u)$

- ω & ϕ cases

$$M_\phi = (M_s + M_u)(u - M_N^2)\left[R^N + e^{i\varphi(u)} F_1^{(s)}(u)\,\tilde{R}^N\right]$$

- ρ^0 case

$$M_\rho = (M_s + M_u)(u - M_N^2)\left[R^N + e^{i\varphi(u)} F_1^{(v)}(u)\,\tilde{R}^N\right]$$

$$+\frac{2}{3} M_u^\Delta (u - M_\Delta^2)\left[R^\Delta + e^{i\varphi_\Delta(u)} F_2^{(v)}(u)\,\tilde{R}^\Delta\right]$$

- *Baryon Regge pole*

$$R^J(s,u) = \alpha_J' \Gamma[J - \alpha_J(u)] \frac{1}{2}\left[1 \pm e^{i\pi(\alpha_J(u) - 0.5)}\right]\left(\frac{s}{s_0}\right)^{\alpha_J(u) - J}$$

- *Δ^+ exchange*

$$M_u^\Delta = \bar{u}(p') \frac{c_1}{m_0} \gamma_5 (\hat{\epsilon} k^\alpha - \hat{k}\epsilon^\alpha) \frac{(\hat{p}' - \hat{k} + M_\Delta)}{(u - M_\Delta^2)} \Pi_{\alpha\beta}^\Delta \times \frac{f_{\rho N \Delta}}{m_\rho} (\hat{\eta} q^\beta - \hat{q}\eta^\beta)\,\gamma_5 u(p)$$

GPD FF for meson-baryon FF

$$F_1^{(s)}(u) = \frac{1}{3}\int_0^1 dx [u(x) + d(x)] x^{-\alpha_q'(1-x)u}$$

$$F_1^{(v)}(u) = \int_0^1 dx [u(x) - d(x)] x^{-\alpha_q'(1-x)u}$$

$$F_2^{(v)}(u) = \frac{G_M(0)}{\kappa_v}\int_0^1 dx \left[\frac{e_u \kappa_u}{N_u}(1-x)^{\eta_u} u(x) - \frac{e_d \kappa_d}{N_d}(1-x)^{\eta_d} d(x)\right] x^{-\alpha_q'(1-x)u}$$

$(\alpha_q' = 0.3\ GeV^{-2})$

N exchange

$$g_\omega^v = 15.6, \qquad g_\omega^t = 0$$

$$g_\phi^v = 3.2, \qquad g_\phi^t = 0$$

$$g_\rho^v = 2.6, \qquad g_\rho^t = 2.6 * 3.7$$

$$R^N = canon. \qquad \alpha_N(u) = 0.9u - 0.365$$

$$\tilde{R}^N = canon. \qquad \tilde{\alpha}_N(u) = 0.9u - 0.56$$

$$\varphi_N(u) = (-65u + 93)\pi/180$$

Δ^+ exchange

$$c_1 = -2.68e, \qquad f_{\rho N\Delta} = 5.05$$

$$G_M(0) = 3.02, \qquad \kappa_V = 3.7$$

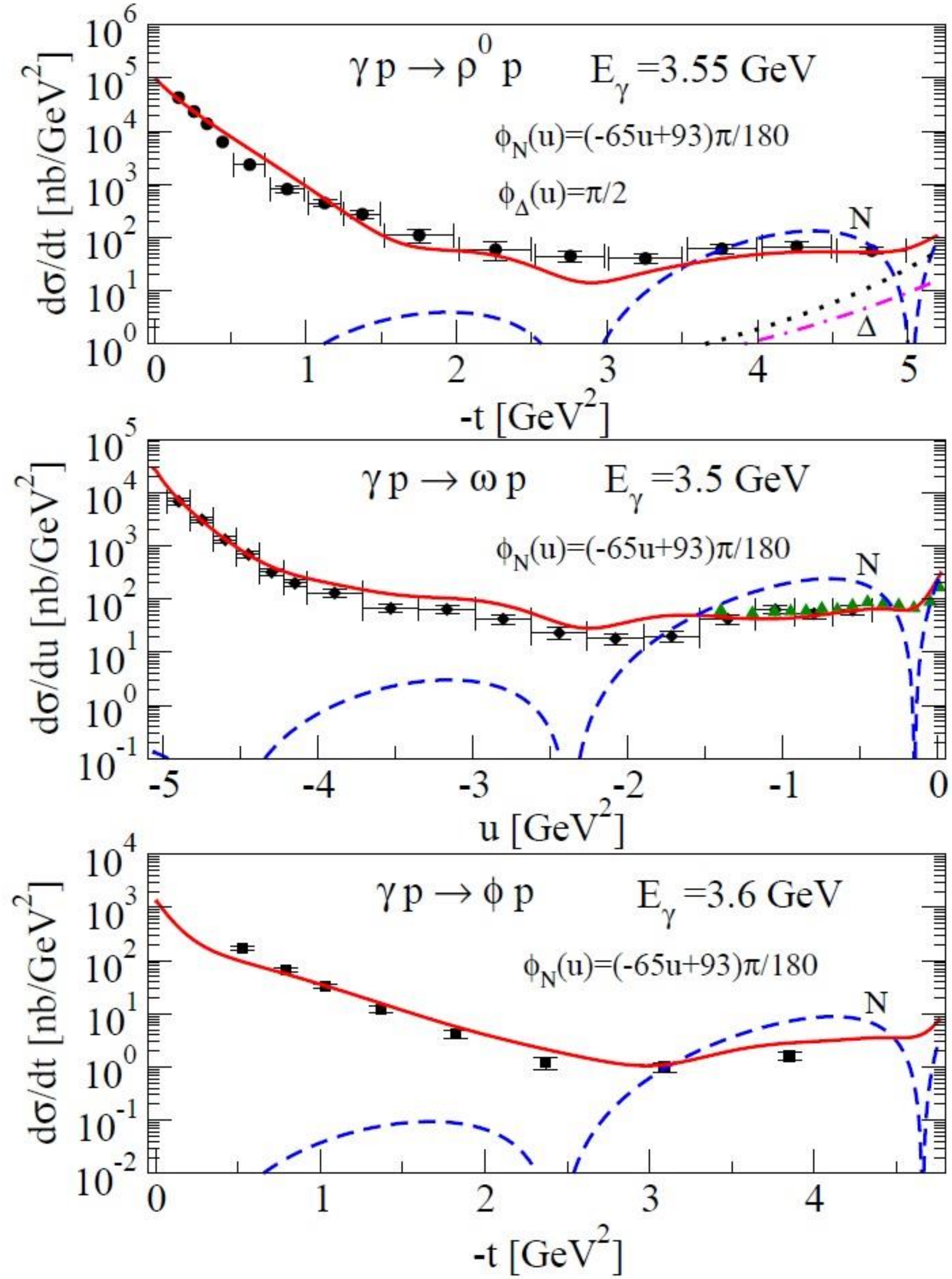
$$\kappa_u = 1.673, \qquad \kappa_d = -2.033$$

$$\eta_u = 1.713, \qquad \eta_d = 0.566$$

$$R^\Delta = complex \qquad \alpha_\Delta(u) = 0.9u - 0.25$$

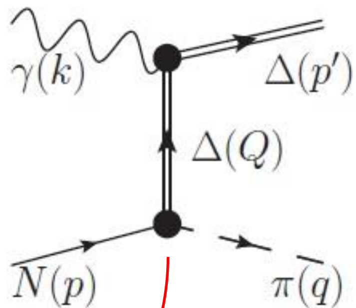
$$\tilde{R}^\Delta = canon. \qquad \tilde{\alpha}_\Delta(u) = 0.9u + 0.2$$

$$\varphi_\Delta(u) = \pi/2$$



$\pi^-\Delta^{++}$ photoproduction

* Study GPD contents of $N\Delta$ axial vector FF in u-channel



$$M_\Delta = M_u^\Delta(u - M_\Delta^2)\left[R^\Delta + e^{i\varphi_\Delta(u)} G_A^{N\Delta}(u)\,\tilde{R}^\Delta\right]$$

Gauge invariance $\quad e_p - e_{\Delta^{++}} - e_{\pi^-} = 0$

$$M_u^\Delta = M_u^{\Delta^{++}} + M_s^p + M_t^{\pi^-} + M_c$$

$M_u^{\Delta^{++}}$ =Full $\gamma\Delta\Delta$ vertex & full Δ propagation $\Pi_\Delta^{\mu\nu}$

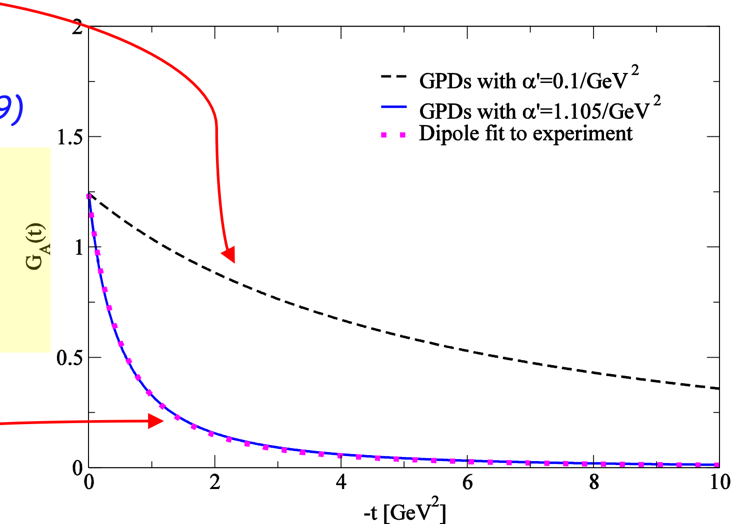
$$G_A^{N\Delta}(u) = \int_0^1 dx\left[\Delta u_v(x,u) - \Delta d_v(x,u)\right] x^{-\alpha_q'(1-x)u}$$

D. de Florian, R. Sassot, M. Stratmann, W. Vogelsang, PRD 80, 034030 (2009)

$$\Delta u_v(x) = 0.677x^{(0.692-1)}(1-x)^{3.34}(1 - 2.18x^{0.5} + 15.87x)$$

$$\Delta d_v(x) = -0.015x^{(0.164-1)}(1-x)^{3.89}(1 + 22.4x^{0.5} + 98.94x)$$

$$G_A^d(t) = \frac{1.24 \pm 0.01}{(1 - t/1.05^2)^2}$$



Δ^{++} *exchange*

$$M_u^{\Delta} = i\frac{f_{\pi N\Delta}}{m_\pi}\bar{u}_\mu(p')\Gamma^{\mu\nu}_{\gamma\Delta\Delta}(k)\frac{\hat{p}' - \hat{k} + M_\Delta}{u - M_\Delta^2}\Pi^{\Delta}_{\nu\beta}\, q^\beta$$

$f_{\pi N\Delta}$=1.7

$$\Gamma^{\mu\nu}_{\gamma\Delta\Delta}(k) = (e_\Delta \hat{\epsilon} g^{\mu\nu} - e_\Delta \epsilon^\mu \gamma^\nu)$$

$$-\frac{e}{4M_\Delta}\left(\kappa_\Delta g^{\mu\nu} + \chi_\Delta \frac{k^\mu k^\nu}{4M_\Delta^2}\right)[\hat{\epsilon},\hat{k}]$$

$$+\frac{e\lambda_\Delta}{4M_\Delta^2}\left[k^\mu k^\nu \hat{\epsilon} - \frac{1}{2}\hat{k}(\epsilon^\mu k^\nu + \epsilon^\nu k^\mu)\right]$$

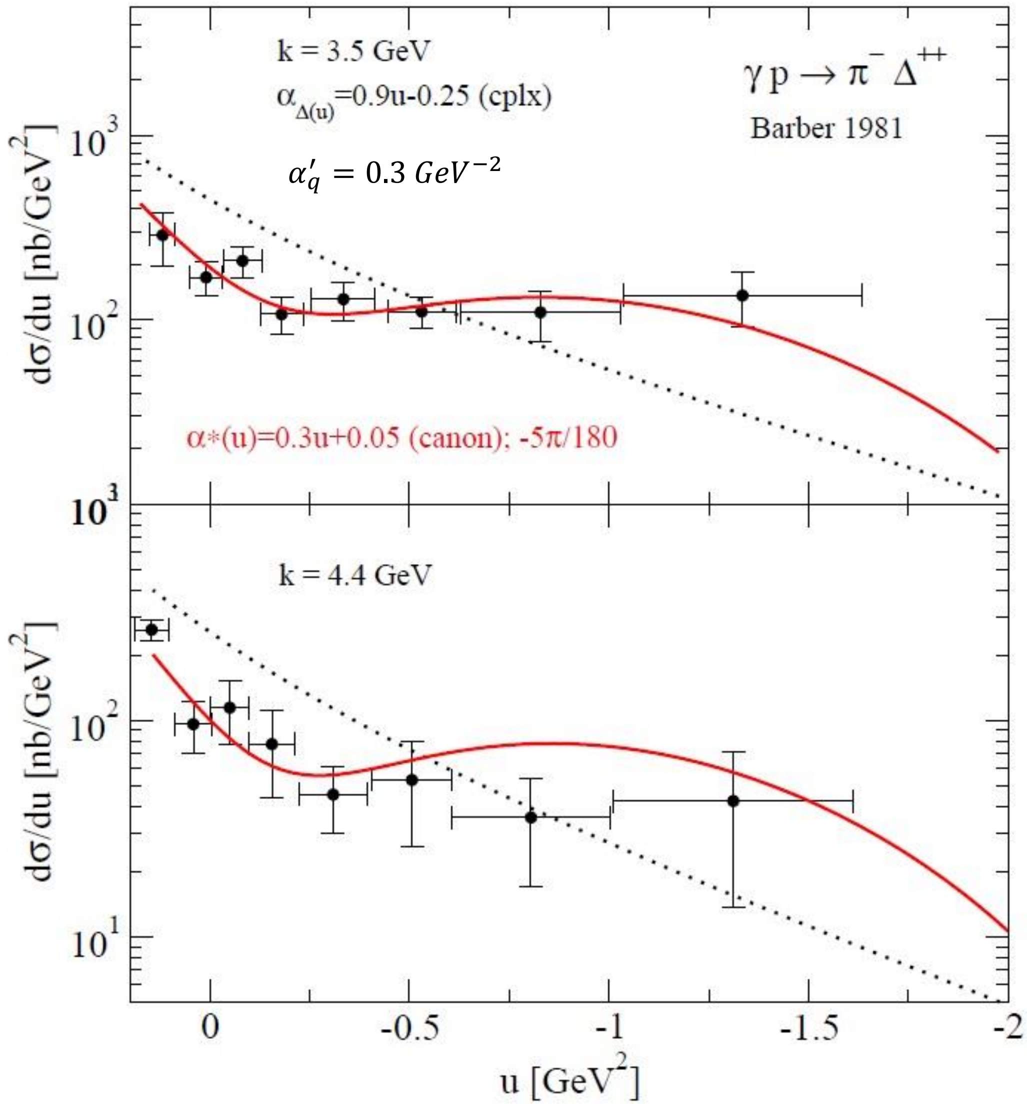
QSR ← K. Azizi, K. Azizi, EPJC61, 311 (2009)

$\kappa_\Delta = 4.34,\ \chi_\Delta = 12.34,\ \lambda_\Delta$=6.18

$R^\Delta = complex$ $\qquad$ $\alpha_\Delta(u) = 0.9u - 0.25$

$\tilde{R}^\Delta = canon.$ $\qquad$ $\tilde{\alpha}_\Delta(u) = 0.3u + 0.05$

$\varphi_\Delta(u) = -5\pi/180$

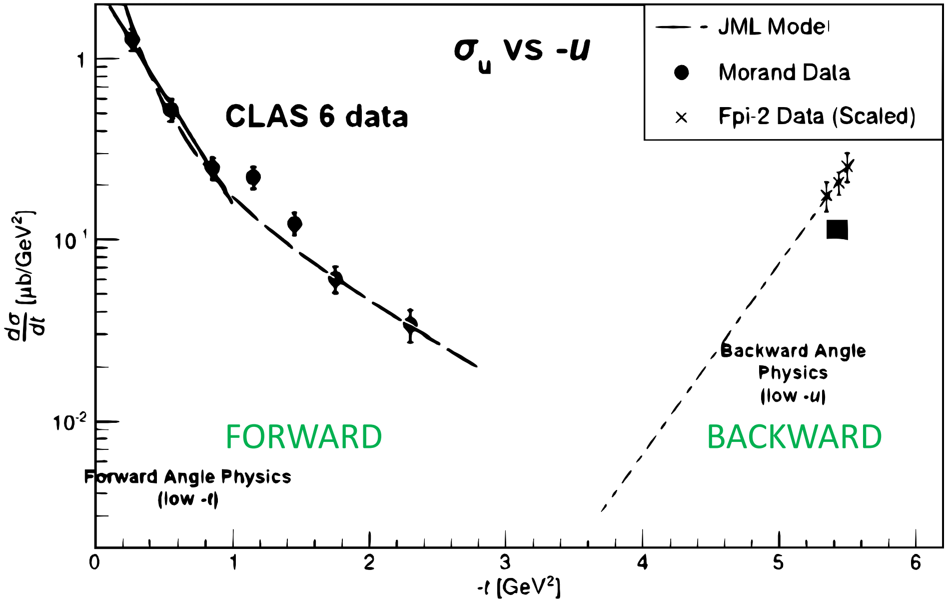


ω Electroproduction (CLAS-6 GeV & Fpi-2/JLab)

$$\gamma^*(k) + p(p) \rightarrow \omega^0(q) + p(p')$$

$$2\pi \frac{d^2\sigma}{dt d\phi} = \frac{d\sigma_T}{dt} + \varepsilon \frac{d\sigma_L}{dt} + \sqrt{2\varepsilon(1+\varepsilon)} \frac{d\sigma_{LT}}{dt} \cos\phi + \varepsilon \frac{d\sigma_{TT}}{dt} \cos 2\phi$$

$$\varepsilon = \left(1 + 2 \frac{|\vec{q}|^2}{Q^2} \tan^2 \frac{\theta_e}{2} \right)^{-1}$$



2. F_π data on backward ω electroproduction

PHYSICAL REVIEW LETTERS **123,** 182501 (2019)

Unique Access to *u*-Channel Physics: Exclusive Backward-Angle Omega Meson Electroproduction

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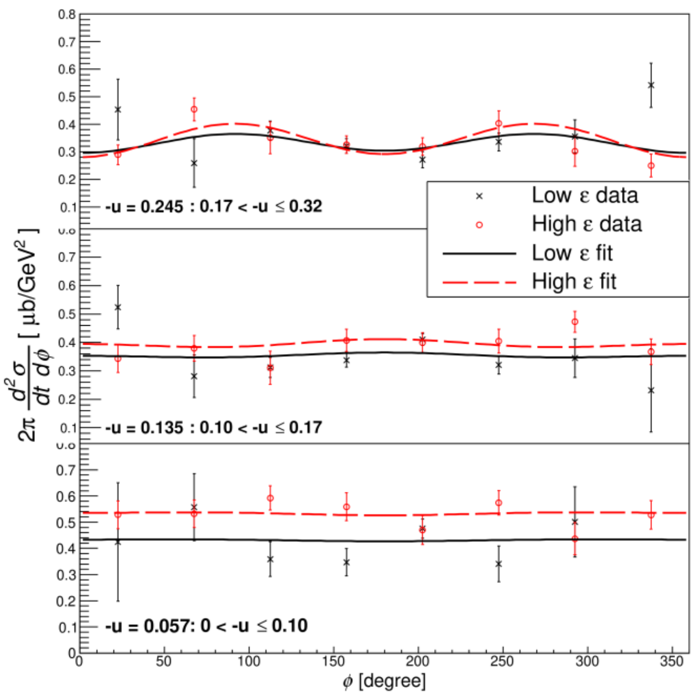
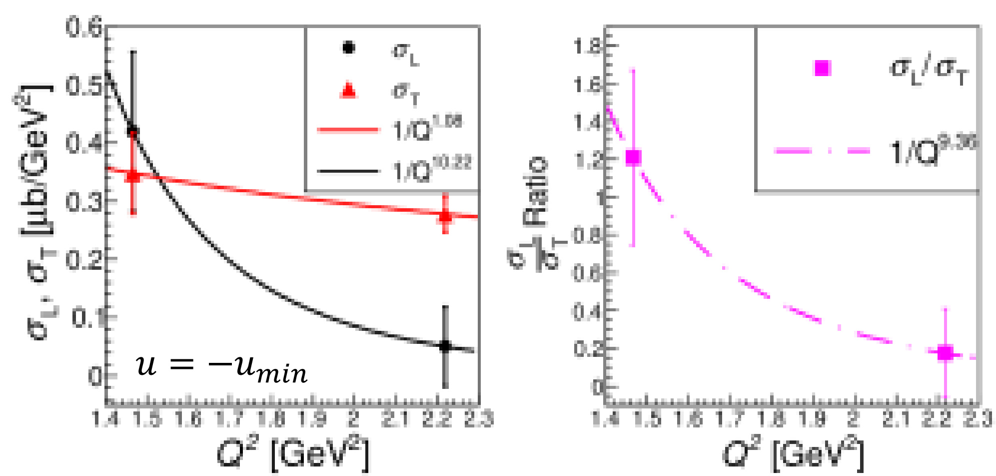
$W = 2.21$ GeV,

$Q^2 = 1.6, 2.45\ GeV^2$



- $\sigma_T \sim 1/Q, \quad \sigma_L \sim 1/Q^8$
- Dominance of σ_T over σ_L ~ TDA ?



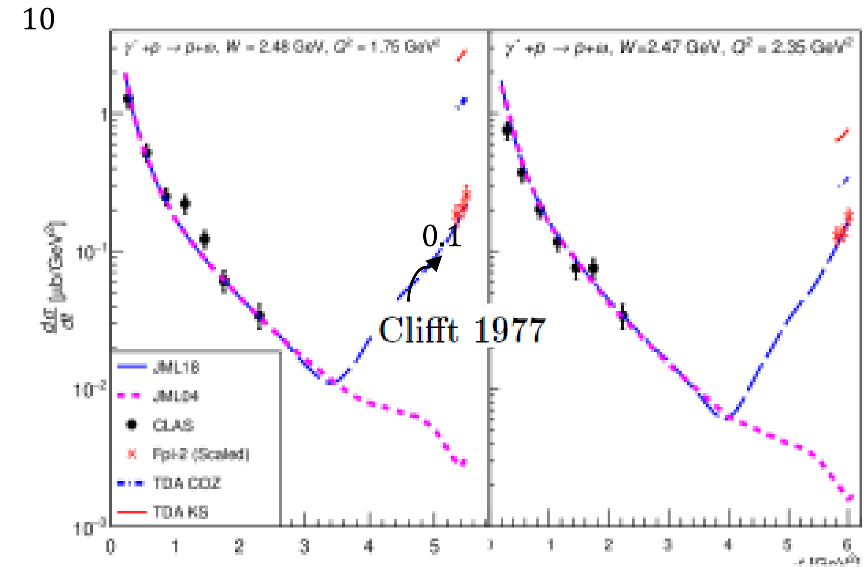
Theory & Experiment for backward $\gamma^* p \to \omega p$

- Regge model by JM Laget

J. M. Laget, PRD 70, 054023 (2004)

J. M. Laget, Prog. Part. Nucl. 111, 103737 (2020)

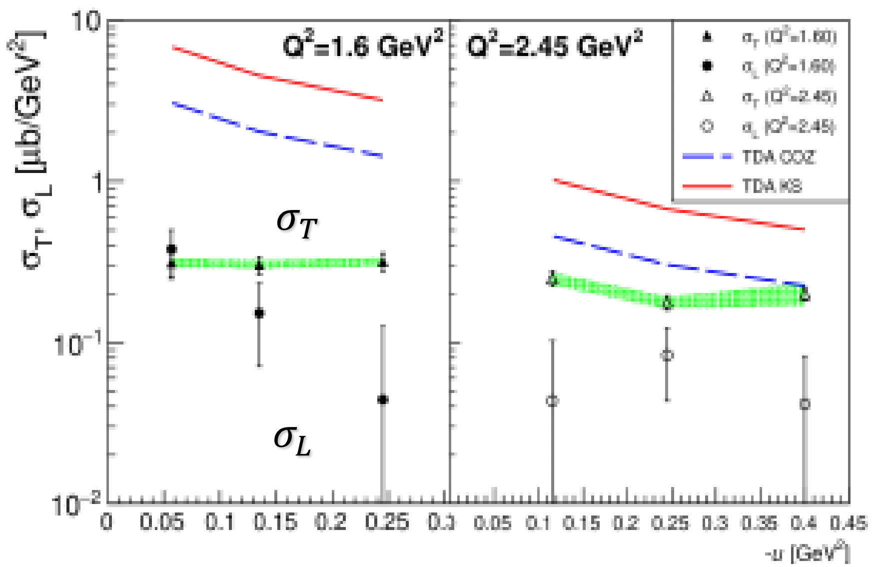
- Meson exchange in the t-ch
- Nucleon exchange in the u-ch
- Cuts in t-ch & u-ch baryon cuts,
- 2 gluon exch



- TDA by Pire, Semenov, Szymanovski

  Phys. Rev. D 91, 094006 (2015)

- σ_T consistency with TDA at Q^2=2.45 GeV^2



Extension to electroproduction

t-ch. exch. as background contribution

1. Nucleon Born terms for electroproduction

$$M_p = \underbrace{(M_s^* + M_u^*)}_{Dipole\ FF}\left(u - M_p^2\right)[R^N(s,u) + e^{i\varphi(u)}\ \underbrace{F_1^{(s)}(u)}_{GPD\ FF}\tilde{R}^N(s,u)]$$

- *EM FF at $\gamma^* NN$ and ωNN vertices*

$$\Gamma_{\gamma^* pp}(k) = e\left(F_1(Q^2)\not{\varepsilon} - \frac{F_2(Q^2)}{4M_p}[\not{\varepsilon}, \not{k}]\right)$$

$$\Gamma_{\omega pp}(q) = g_{\omega pp}^{v}\not{\eta} + \frac{g_{\omega pp}^{t}}{4M_p}[\not{\eta}, \not{q}]$$

- *Gross-Riska prescription for gauge invariance of nucleon charge form factor*

$$F_1(Q^2)\not{\varepsilon} \to [F_1(Q^2) - F_1(0)]\left(\not{\varepsilon} - \not{k}\frac{\varepsilon\cdot k}{k^2}\right) + F_1(0)\not{\varepsilon}$$

2. Parton contribution to nucleon Born terms

- Nucleon electromagnetic form factors at $\gamma^* NN$ vertex

(1) PDF

$$F_{1,2}^{p}(Q^2) = e_u F_{1,2}^{u}(Q^2) + e_d F_{1,2}^{d}(Q^2) \qquad \left(Q^2 = -k^2\right)$$

Following concept of collinear factorization

(2) Dipole-form factor for consistency with photoproduction $Q^2 = 0$

$$F_1(Q^2) = \left(\frac{1+\tau\mu_p}{1+\tau^2}\right)\left(\frac{1}{1+Q^2/\Lambda_p^2}\right)^2, \quad F_2(Q^2) = \left(\frac{\mu_p - 1}{1+\tau^2}\right)\left(\frac{1}{1+Q^2/\Lambda_p^2}\right)^2$$

- ωNN strong coupling form factor

(1) PDF

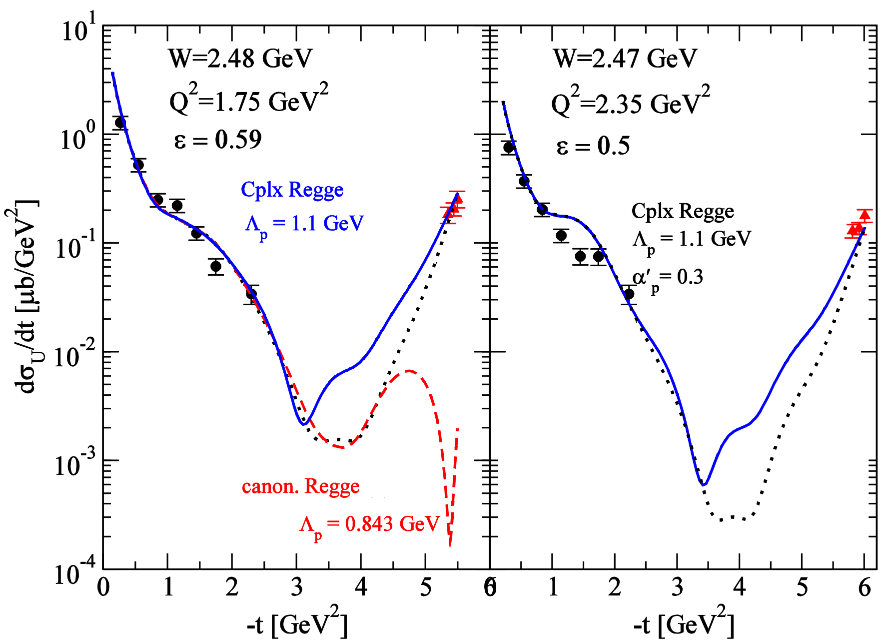
$$F_{\omega pp}(u) \equiv F_1^{(s)}(u) = F_1^p(u) + F_1^n(u) = (e_u + e_d)[u(u) + d(u)]$$

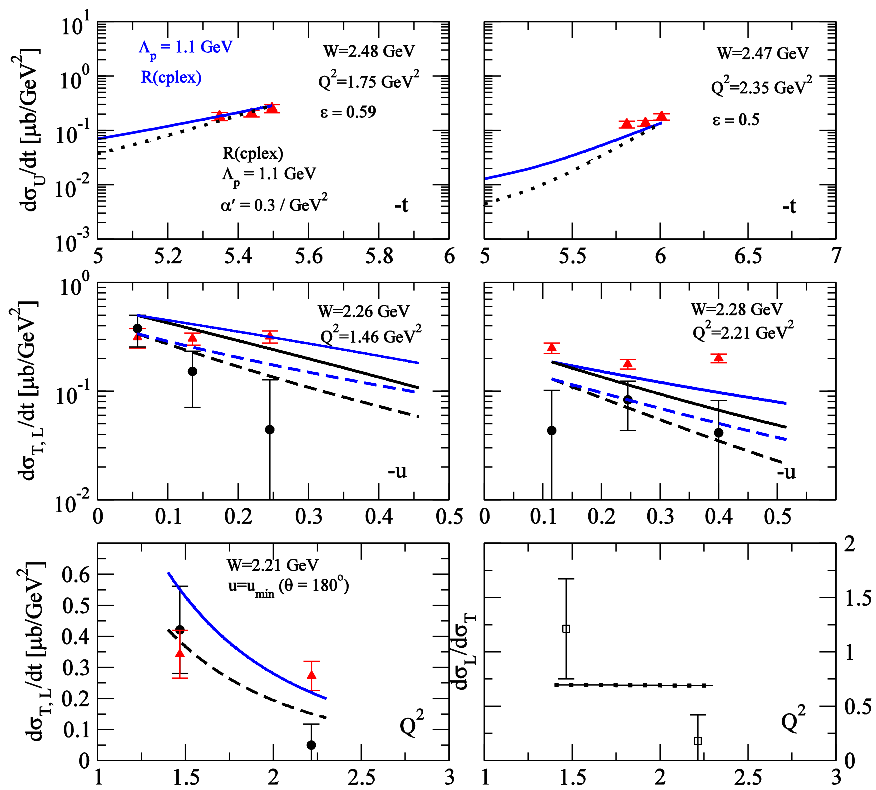
$$\left(u = (p-q)^2\right)$$

3. Result: Conventional Model

Production mechanism

- Nucleon exch. w/o partons
- Meson exch in t-ch
- Conventional model fails with on-shell cutoff-mass for EMFF



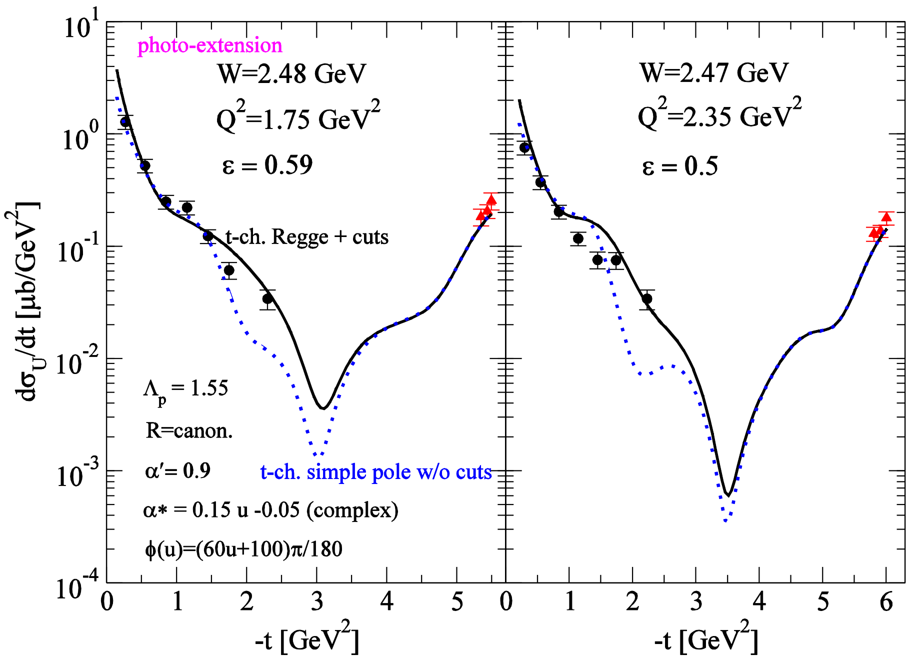


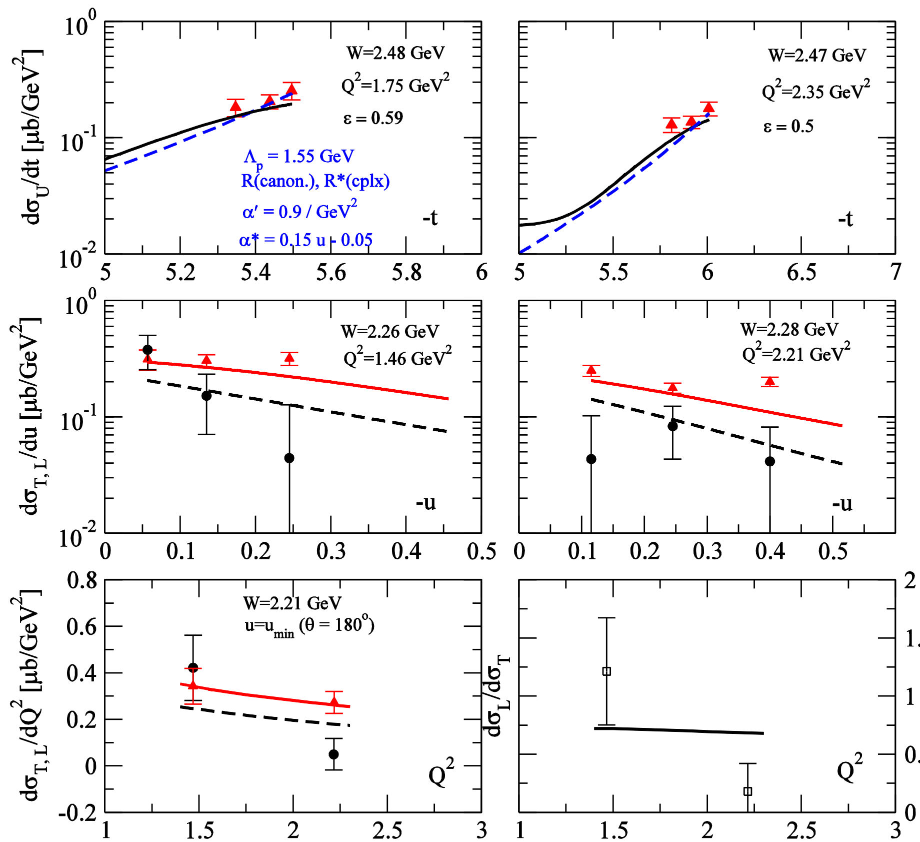
4. Result: Regge + parton Model

Production mechanism

- Nucleon EMFF $\Lambda_p = 1.55$ GeV consistent with $\gamma^* p \to \pi^+ n$
- Meson exch in t-ch
- Parton structure in ωNN FF

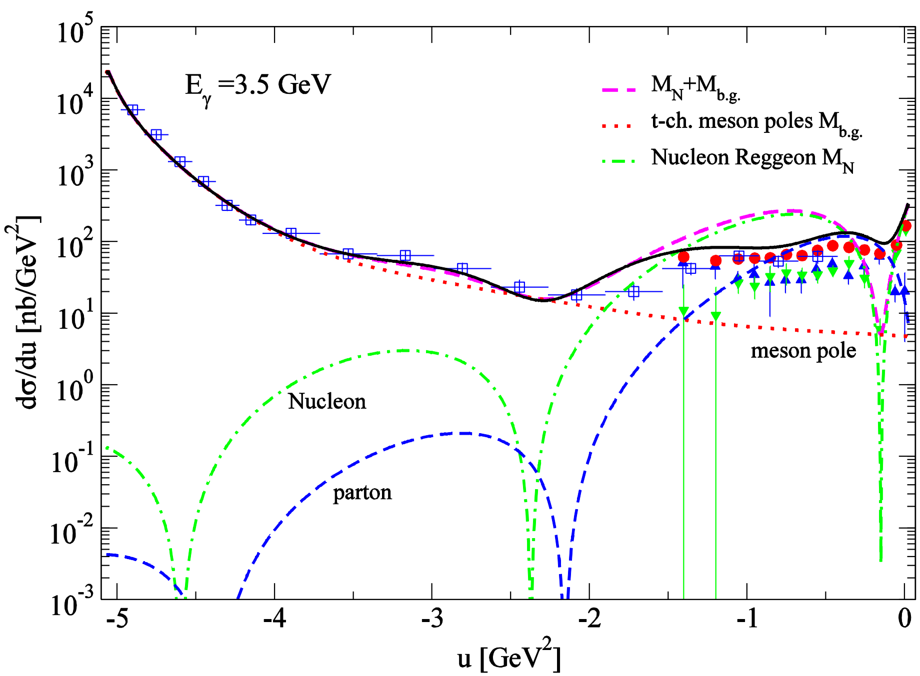
$$\phi(u) = (60u + 100)\pi / 180$$

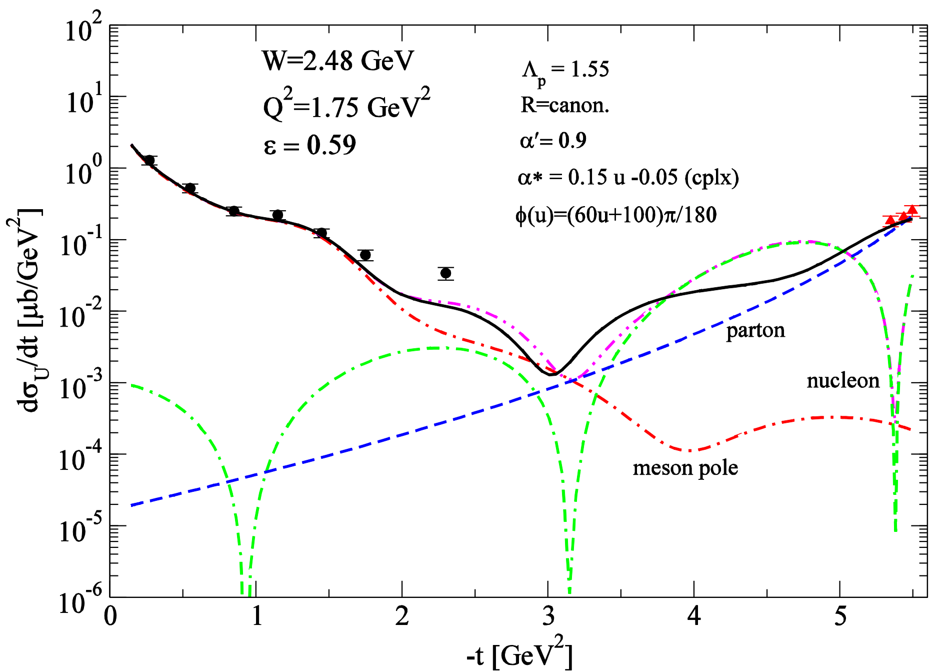




5. *Result*: Photoproduction vs. electroproduction

- t-ch simple poles
- u-ch nucleon Reggeon
- u-ch parton contrib.
- Mid-angle region





6. Result: Regge vs. Nucleon transition distribution amplitude (TDA)

B. Pire, Kirill M. Semenov-Tian-Shansky, L. Szymanowski

Phys. Rev. D 91, 094006 (2015)

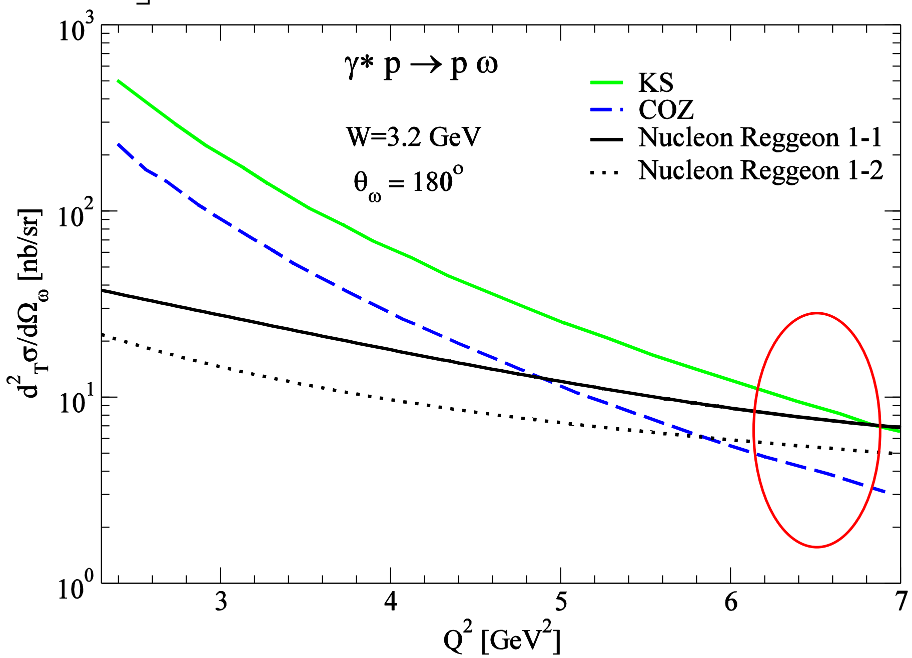
$$\frac{d^2\sigma_T}{d\Omega_\omega} = \frac{\Lambda(s, m_\omega^2, M^2)}{128\pi^2 s(s-M^2)} \frac{1}{2} |M_T|^2$$

$$|M_T|^2 = |D|^2 \frac{1}{Q^6} \frac{2(1+\xi)}{\xi} \left[\sum_{k,l} \mathrm{I}^{(k)} \mathrm{I}^{(l)*} C_{kl}(\xi, m_\omega^2, M^2, \Delta_T^2) \right]$$

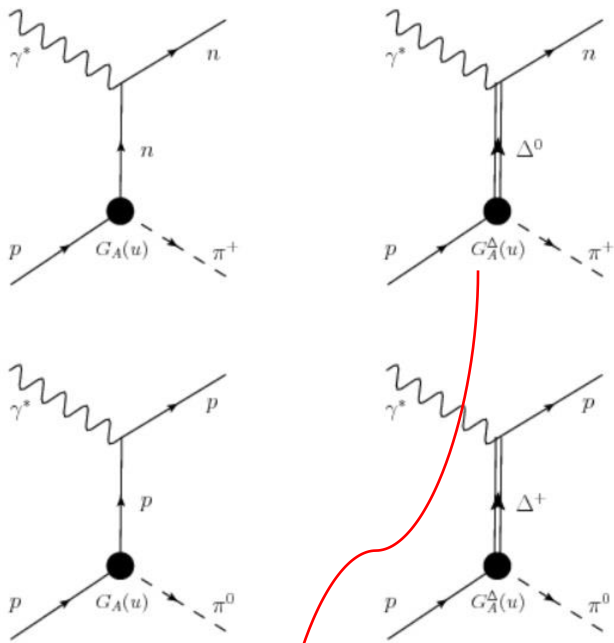
$$\mathrm{I}^{(k)}(\xi, \Delta^2) = \int \left(2\sum_{\alpha=1}^{7} T_\alpha^{(k)} + \sum_{\alpha=8}^{14} T_\alpha^{(k)} \right)$$

Test these signs in experiments

- Dominance of σ_T over σ_L by $1/Q^2$
- $\frac{d^2\sigma_T}{d\Omega_\omega} \sim 1/Q^8$-scaling for fixed x_B



π electroproduction with CLAS 6



- $M(\gamma^* p \to \pi^+ n) = \sqrt{2}\, M_n - \frac{\sqrt{2}}{3} M_{\Delta^0}$

$$M_n = M_u^*(n)\,(u - M_n^2)(R^N + e^{i\varphi(u)} G_A^N(u)\tilde{R}^N)$$

$$M_{\Delta^0} = M_u^*(\Delta^0)\,(u - M_\Delta^2)(R^\Delta + e^{i\varphi_\Delta(u)} G_A^\Delta(u)\tilde{R}^\Delta)$$

$$M_u^\Delta = \bar{u}(p')F_\Delta(Q^2)\frac{C_1}{m_0}\gamma_5\left(\hat{\epsilon}k^\alpha - \hat{k}\epsilon^\alpha\right) \times \frac{(\hat{p}' - \hat{k} + M_\Delta)}{(u - M_\Delta^2)}\Pi_{\alpha\beta}^\Delta \frac{i f_{\pi N\Delta}}{m_\pi} q^\beta u(p)$$

$$F_\Delta(Q^2) = \left(\frac{1}{1 + \frac{Q^2}{\Lambda_\Delta^2}}\right)^2, \quad \Lambda_\Delta^2 = \Lambda_N^2 = 1.55\ GeV^2$$

$$G_A^{N\Delta}(u) = G_A^N(u)$$

$$G_A^{N\Delta}(u) = \int_0^1 dx[\Delta u - \Delta d]\, x^{-\alpha_q'(1-x)u}$$

$$G_A^{N\Delta}(u) = \int_0^1 dx[2\Delta u + \Delta d] x^{-\alpha_q'(1-x)u}$$

- $M(\gamma^* p \to \pi^0\, p) = \sqrt{2}\, M_p + \frac{2}{3} M_{\Delta^+}$

$$M_p = (M_s^* + M_u^*)(p)\,(u - M_p^2)(R^N + e^{i\varphi_N(u)} G_A^N(u)\tilde{R}^N)$$

$$M_{\Delta^+} = M_u^*(\Delta^+)\,(u - M_\Delta^2)(R^\Delta + e^{i\varphi_\Delta(u)} G_A^\Delta(u)\tilde{R}^\Delta)$$

K. Park et al. (CLAS Collaboration), Phys. Lett. B780, 340 (2018)

N *exchange*

$g_{\pi NN} = 13.4$

$R^N = complex \qquad \alpha_N(u) = 0.9u - 0.365$

$\tilde{R}^N = complex \qquad \tilde{\alpha}_N(u) = 0.9u - 0.56$

$\varphi_N(u) = (-65u + 100)\pi/180$

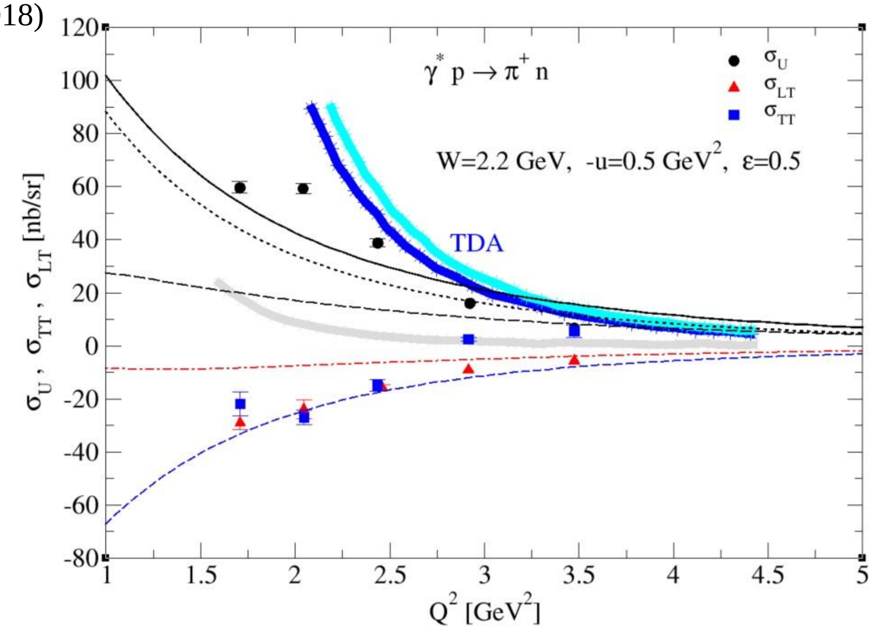
Δ^+ *exchange*

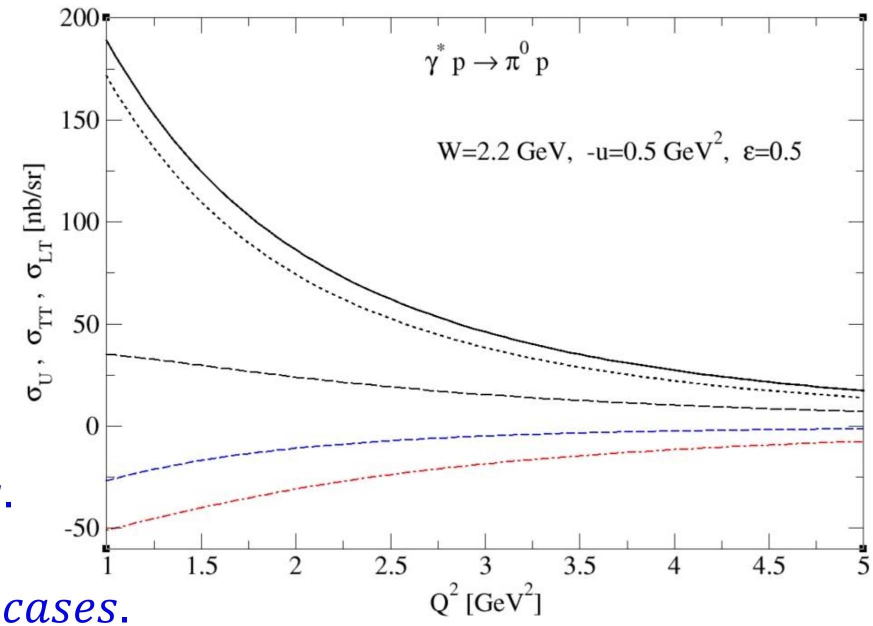
$c_1 = -2.68e, \qquad f_{\pi N\Delta} = 2.2$

$R^\Delta = complex \qquad \alpha_\Delta(u) = 0.9u - 0.25$

$\tilde{R}^\Delta = complex \qquad \tilde{\alpha}_\Delta(u) = 0.1u + 0.5$

$\varphi_\Delta(u) = 30\pi/180$





Comments

- *π^0 cross sections are larger than π^+ cases.*
- *σ_{LT} & σ_{TT} are reversed between π^0 and π^+ cases.*

Summary & conclusions

- To simulate NINA data on backward photoproduction the Regge+parton model considers PDF at the meson-baryon vertex form factor in the u-channel nucleon (and delta) Reggeon.

- The Regge+parton model provides an economic way to plot empirical cross sections for backward hadron reaction.

- Application to pi delta photoproduction provide the axial vector contents of helicity parton distributions, while the case of vector meson production leads to the vector contents of unpolarized parton distributions at high energies and large Q^2. More data are needed to constrain model parameters, e.g. the relative phase between hadron and partons.

- Dipole type of nucleon EM form factors are favored for consistency with photoproduction, the Regge model with GPD form factors at meson-baryon vertex is extended to investigate parton dynamics in backward pion and omega electroproduction experiments at JLab.

- Regge approach with hadron form factor parameterized by PDF can be a tool complementary to GPD/TDA to analyze experiments on parton structures at high enough $s >> |t|$ and large $-t$ (small $-u$) such as CLAS-12 upgrade, JPARC, and future EIC.

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