Regge phenomenology of ω photoproduction

Features from t-ch. Regge poles at forward and from u-ch. Regge poles at backward angles

2017. 11. 2 @ JLab workshop

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in collaboration with

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Outline

- Features of $\gamma N \to \omega N$ distinctive from ρ^0 and φ cases in low energy and wide angles;

- Motivation : Systematic approach to describe reaction $\gamma N \to \omega N$

  - t-ch. meson Regge pole in the forward direction

    Pion dominance with absorption mechanism from cuts

  - u-ch. baryon Regge pole in the backward direction

    Nucleon exch. with filled-up mechanism from partons

- Summary and outlooks

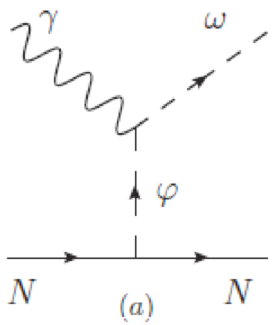
I. Photoproduction of $\gamma p \rightarrow \omega p$ at small $-t$

- AT FORWARD ANGLES

  - Reggeized model for meson exchanges

B.-G. Yu and K.-J. Kong, arXiv:1710.04511[hep-ph]

$$\mathcal{M}_{\varphi} = (\pi + f_1) + (\sigma + f_2 + \mathbb{P})$$



meson	trajectory(α_φ)	phase factor	$g_{\gamma\varphi\omega}$	$g_{\varphi NN}$
π	$0.7(t - m_\pi^2)$	$e^{-i\pi\alpha_\pi}$	-0.69	± 13.4
σ	$0.7(t - m_\sigma^2)$	$(1 + e^{-i\pi\alpha_\sigma})/2$	-0.17	14.6
f_2	$0.9(t - m_{f_2}^2) + 2$	$(1 + e^{-i\pi\alpha_{f_2}})/2$	0.0376	6.45; 0.0
f_1	$0.028\,t + 0.9$	$(-1 + e^{-i\pi\alpha_{f_1}})/2$	0.18	2.5

- σ exch. for natural parity cross section

- Feature of over dominating π exchange of unnatural parity

  with well-known cpl. const.

- Need of absorption mechanism

- **Regge cuts for π exch.**

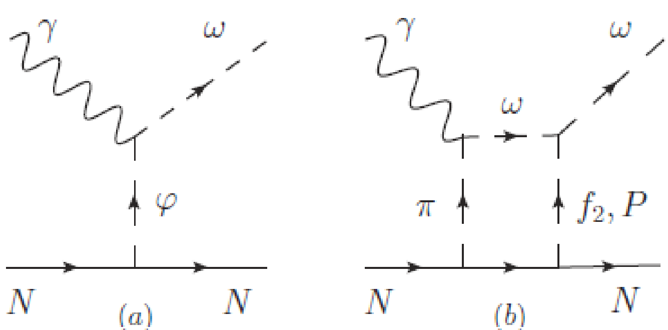
A. Donnachie and Yu. S. Kalashnikova, Phys. Rev. C **93**, 025203 (2016)

- Elastic cuts

$$\mathcal{M}_\pi^{cut} = \mathcal{M}_\pi \left[\mathcal{R}^\pi(s,t) + \sum_{\varphi = f_2, \mathbb{P}} C_\varphi \, e^{d^\varphi \, t} e^{-i\frac{\pi}{2}\alpha_c^\varphi(t)} \left(\frac{s}{s_0}\right)^{\alpha_c^\varphi(t)-1} \right]$$

- **cut trajectory**

$$\alpha_c^\varphi(t) = \frac{\alpha'_\pi \alpha'_\varphi}{\alpha'_\pi + \alpha'_\varphi} t + (\alpha_\pi(0) + \alpha_\varphi(0) - 1)$$

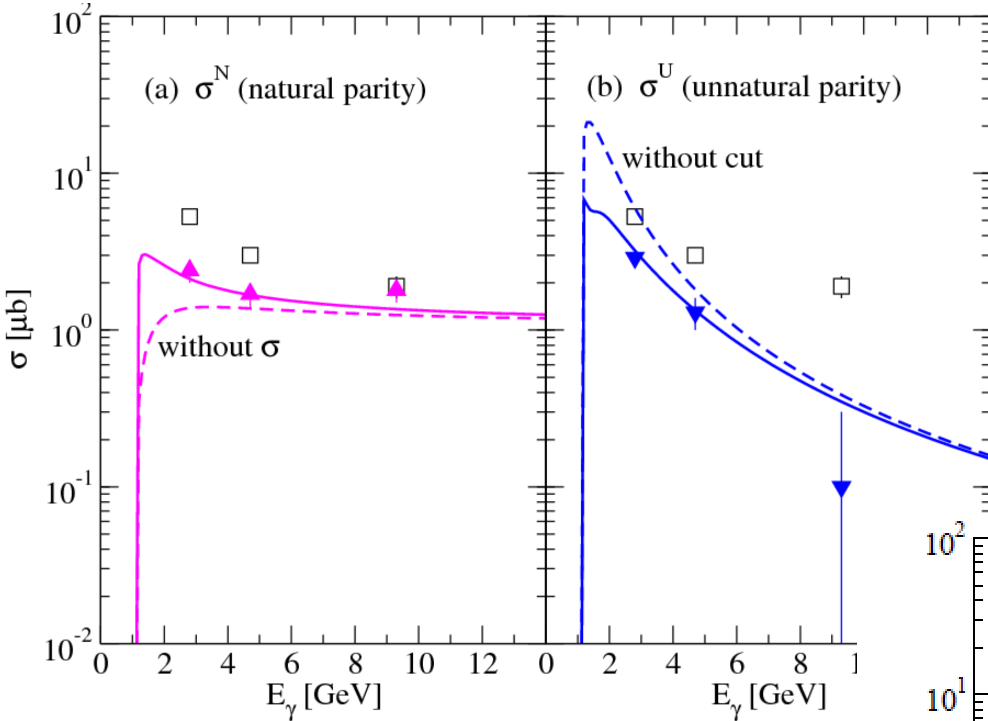


Reggeons **cuts from elastic scattering**

Cut parameters C_φ and d_φ given in units GeV^{-2}.

Reaction	Cut	C_φ	d_φ
γp	π-f_2	41	2.2
	π-$\mathbb{P}$	-2.5	2
γn	π-f_2	32.5	2.2
	π-$\mathbb{P}$	2	2

Natural & unnatural parities of $\gamma p \to \omega p$

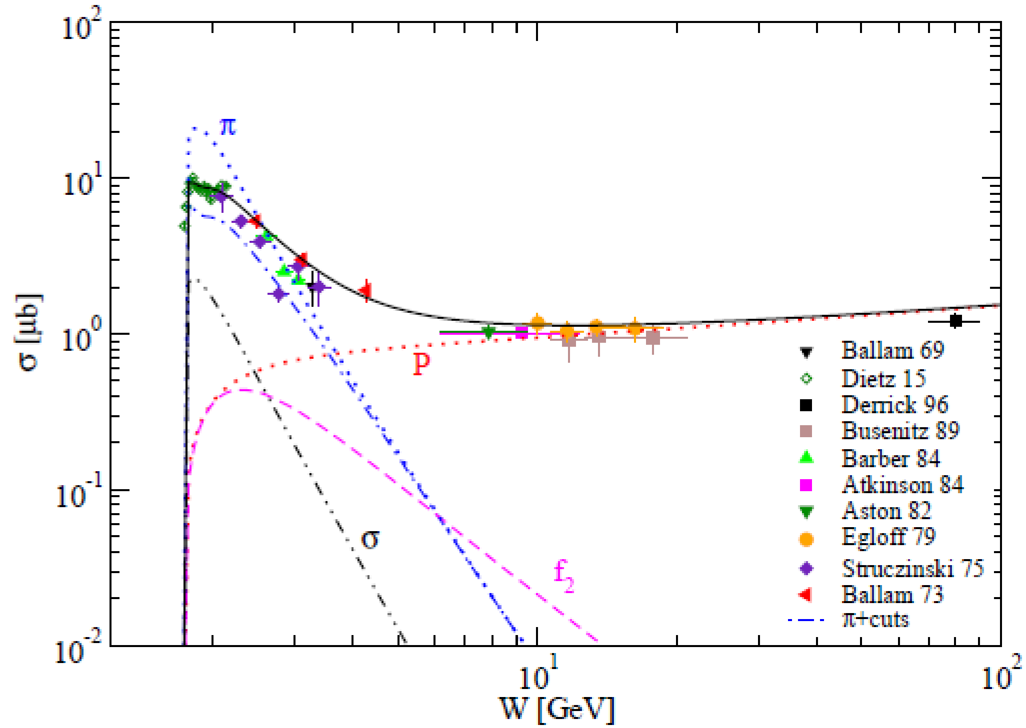


- Overdominance of π exch.
- Need of absorptive cuts for π
- Need of σ exch. for natural parity

- Dependence of Pomeron on f_ω

$$\frac{1}{f_\rho} : \frac{1}{f_\omega} : \frac{1}{f_\phi} = 3 : 1 : -\sqrt{2}$$

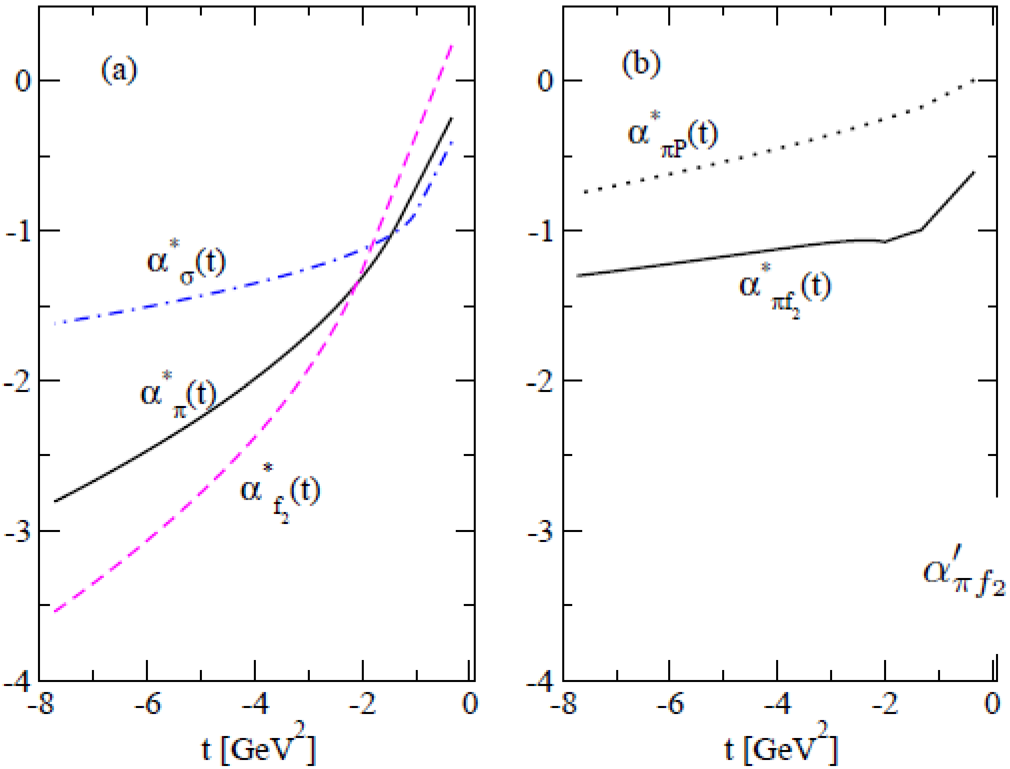
$$f_\rho = 5.2 \qquad f_\omega = 15.6 \qquad f_\phi = -13.4$$



Scaling of differential cross sections $\gamma p \to \omega p$

▶ **Nonlinear trajectory for saturation at large $-t$**

$$\alpha^*(t) = c_1 + c_2\sqrt{t_1 - t}$$



- boundary conditions at the saturation point t_0

$$\alpha^*(t_0) = \alpha(t_0)$$

$$d\alpha^*(t_0)/dt = d\alpha(t_0)/dt$$

- π-f_2 cut trajectory

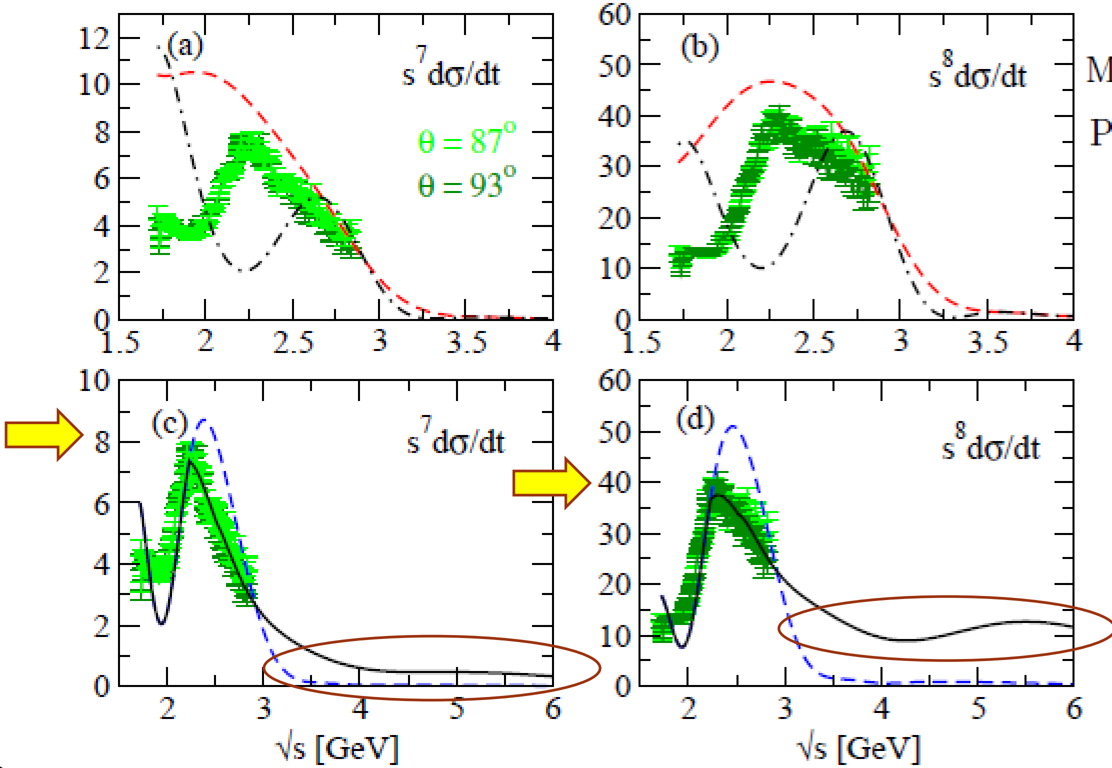
$$\alpha'_{\pi f_2} = \frac{\alpha'^*_{\pi}\alpha'^*_{f_2}}{\alpha'^*_{\pi} + \alpha'^*_{f_2}}, \quad \alpha^0_{\pi f_2} = \alpha^*_{\pi}(0) + \alpha^*_{f_2}(0) - 1$$

- π-$\mathbb{P}$ cut

$$\alpha'_{\pi\mathbb{P}} = \frac{\alpha'^*_{\pi}\alpha'_{\mathbb{P}}}{\alpha'^*_{\pi} + \alpha'_{\mathbb{P}}}, \quad \alpha^0_{\pi\mathbb{P}} = \alpha^*_{\pi}(0) + \alpha_{\mathbb{P}}(0) - 1$$

Energy dependence of scaled differential cross sections

- s^7 power from direct photon cpl. and s^8 from VMD
- Role of cuts and complex phase for π
- Different scaling between s^7 and s^8 power laws over $\sqrt{s} \approx 3$ GeV
- A criterion to discern priority between direct photon cpl. and VMD



M. Williams *et al.* (CLAS Collaboration), Phys. Rev. C **80**, 065208 (2009).

Below 3 GeV $s^8 d\sigma / s^7 d\sigma \simeq 5$ **but the ratio is not maintained over 3 GeV** $s^8 d\sigma / s^7 d\sigma \simeq 30$

- Measurement over $W \approx 3$ GeV

II. Photoproduction of $\gamma p \to \omega p$ at small $-u$

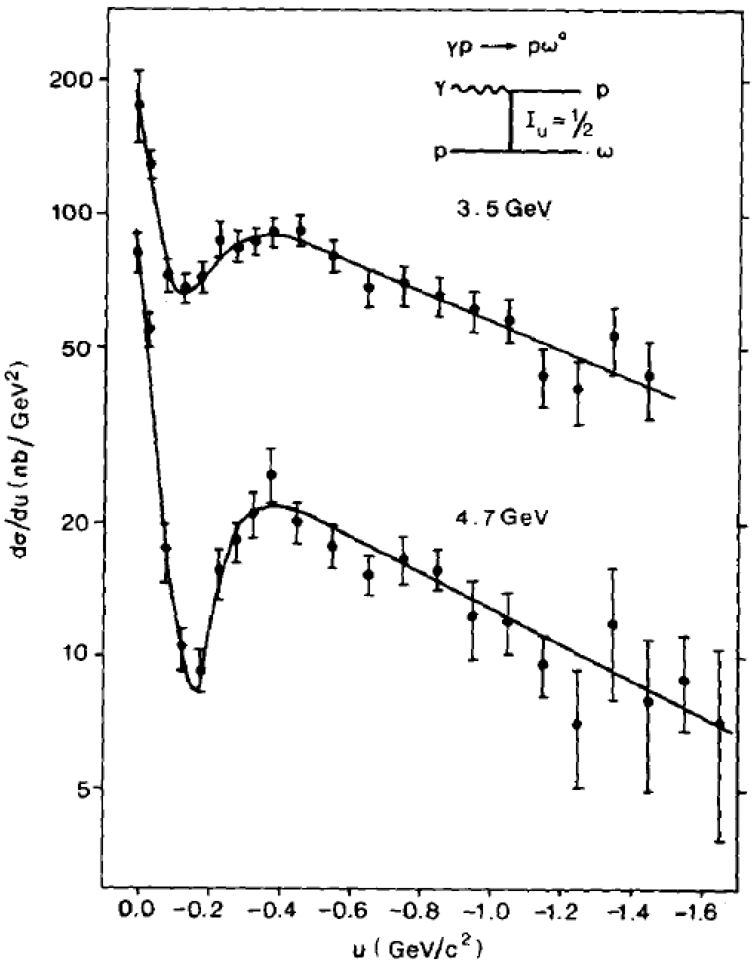
■ AT BACKWARD ANGLES

Theories and experiments are rare for backward ω photoproduction

NINA data for $-1.8 < u < 0.02$ GeV^2 at E_γ =3.5, 4.7 GeV

(Daresbury Lab. by Clifft 1977)

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



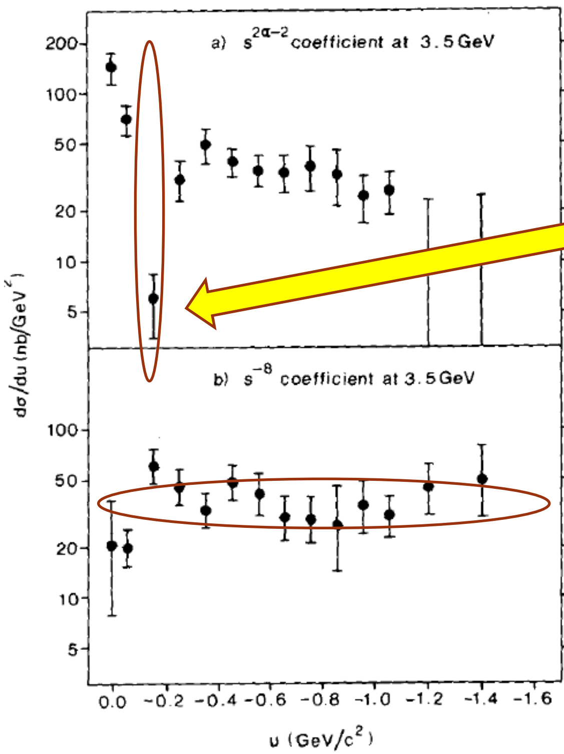
► Exp. Observations:

- 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

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

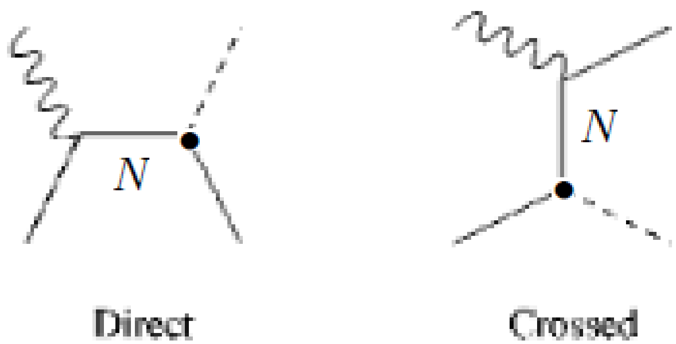
$$\frac{d\sigma}{du} = \left| A(u) s^{\alpha(u)-1} + B e^{i\phi(u)} s^{-4} \right|^2$$



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

Reggeization of nucleon in u-ch. exchange

- **Gauge invariant Born terms**



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

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

$$\Gamma_{\gamma NN} = e\left(e_N\not{\epsilon} - \frac{\kappa_N}{4M_N^2}[\not{\epsilon},\not{k}]\right), \qquad e_N = 1,\ \kappa_N = 1.79$$

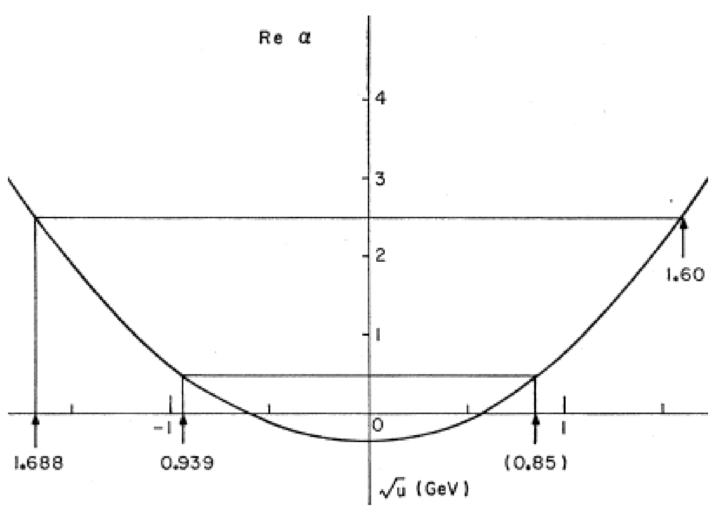
$$\Gamma_{\omega NN} = g_{\omega NN}\left(\not{\eta}^* + \frac{\kappa_\omega}{4M_N^2}[\not{\eta}^*,\not{q}]\right) \qquad g_{\omega NN} = 15.6,\ \kappa_{\omega NN} = 0$$

- **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** $\qquad \alpha_N^+(\sqrt{u}) = 0.9\,u - 0.365$
- **A dip at** $u = -0.15$ **GeV**^{2} **from NWS zero,** $1 + e^{-i\pi(\alpha_N(u)-0.5)} = 0$



Fix background from meson exchanges

- Reggeized model for nucleon exchange

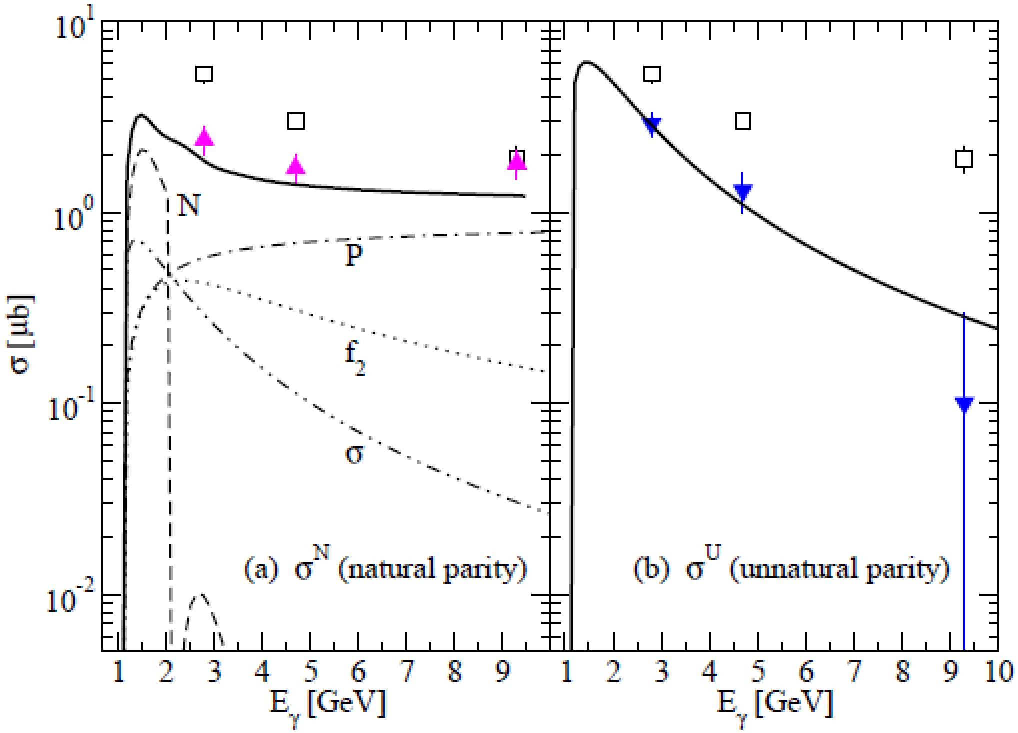
$$\mathcal{M} = \mathcal{M}_N + \text{background}$$

- Background from t meson exch. with cutoff functions $F_\varphi(t) = \left(\frac{t - m_\varphi^2}{t - \Lambda_\varphi^2}\right)^n$
- Reggeized f_2

$$\mathcal{M}_{\text{nat.}} = \mathcal{M}_N + M_\sigma + M_{f_2} + M_{\mathbb{P}}\,,$$
$$\mathcal{M}_{\text{unnat.}} = M_\pi + M_{f_1}\,,$$

- Cutoff masses

Meson	Mass	n	Λ_φ	$g_{\gamma\varphi\omega}$	$g_{\varphi NN}$
π	139.57	2	720	−0.69	13.4
σ	500	1	650	−0.17	14.6
f_1	1281.9	1	1300	0.18	2.5



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**

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

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

- ▶ nucleon isoscalar form factor $\quad F_s = F_1^p + F_1^n$
- ▶ quark contents $\quad F_1^p = e_u u + e_d d\,, \quad F_1^n = e_u d + e_d u$

- **Regge-like ansatz $R2$ for parton density** M. Guidal *et al.*, Phys. Rev. D **72**, 054013 (2005)

$$q(u) = \int dx q_v(x) x^{-(1-x)\alpha'(u-u_0)}\,, \qquad \alpha' = 0.3\ \mathrm{GeV}^2$$

- **Unpolarized parton distributions** from MRST2002 global NNLO fit

A. D. Martin, Phys. Lett. B **531**, 216 (2002)

$$u_v = 0.262x^{-0.69}(1-x)^{3.5}\left(1 + 3.8x^{0.5} + 37.65x\right)\,,$$

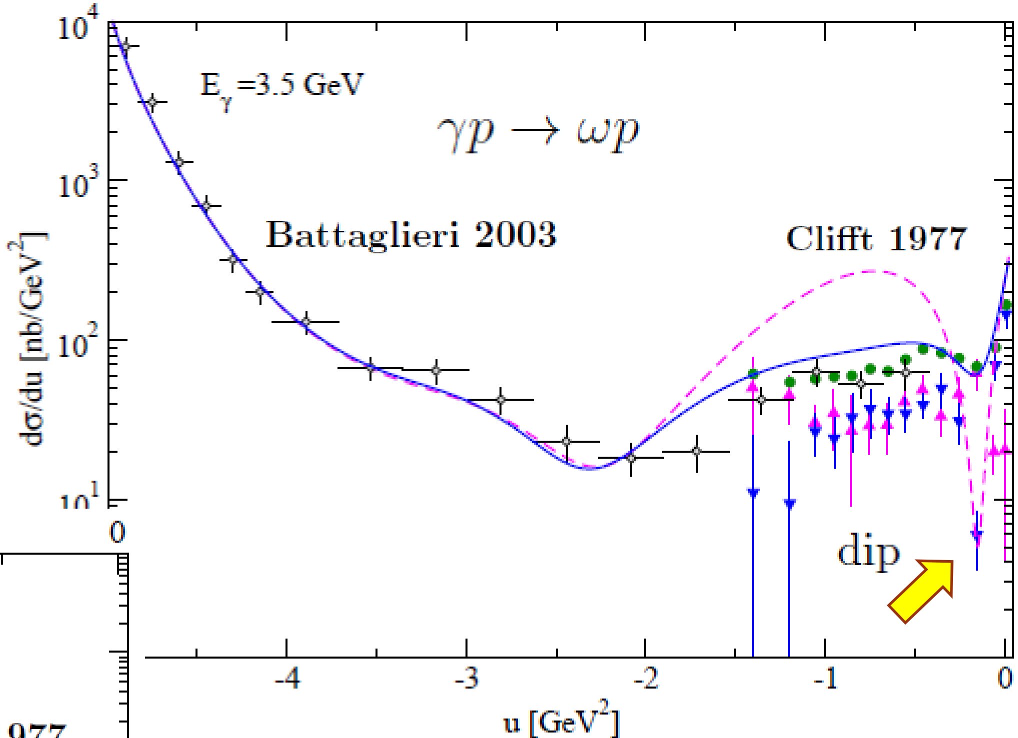
$$d_v = 0.061x^{-0.65}(1-x)^{4.03}\left(1 + 49.05x^{0.5} + 8.65x\right)$$

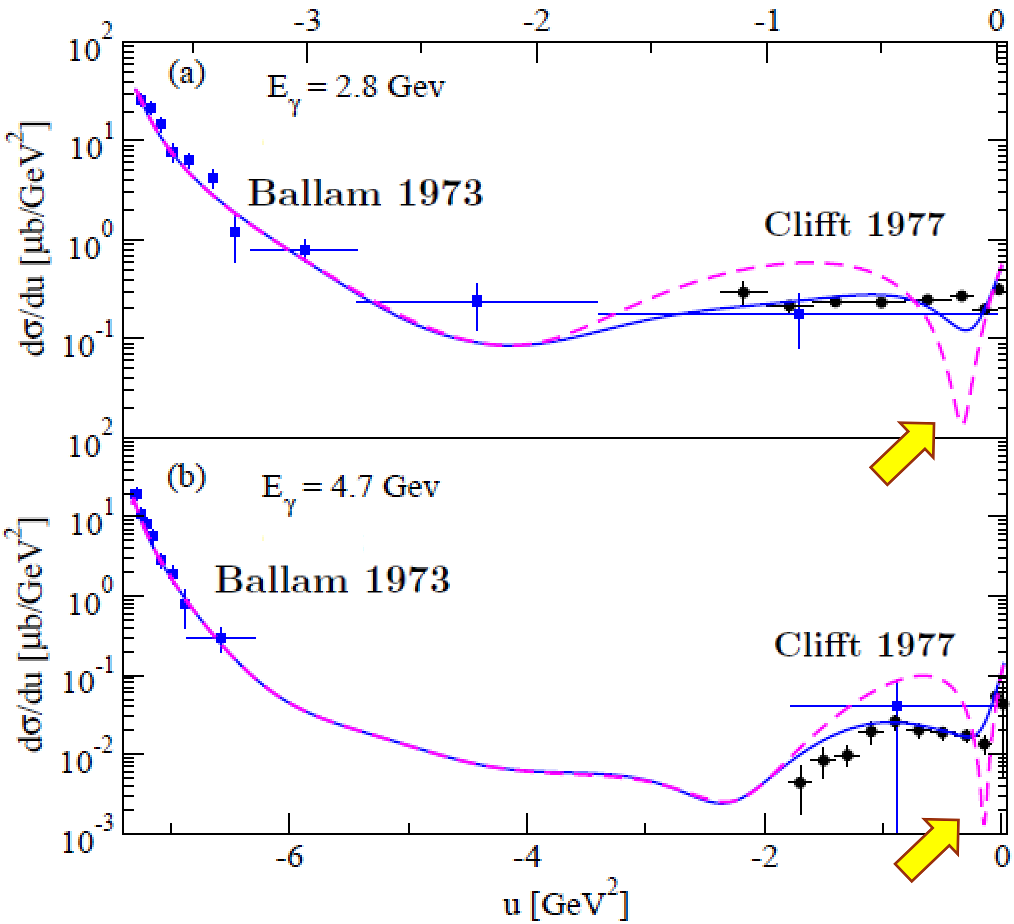
- ▶ relative phase between hadron and parton $\quad \phi(u) = (a + bu)\dfrac{\pi}{180}$

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

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

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





▶ Change of trajectory in the present of partons

$$\tilde{\alpha}_N(u) = 0.9\,u - 0.5$$

▶ Parameters fit to data

$a = 90, \quad b = -60 \quad \text{for } E_\gamma = 2.8\ \text{GeV}$

$a = 100, \quad b = -60 \quad \text{for } E_\gamma = 3.5\ \text{GeV}$

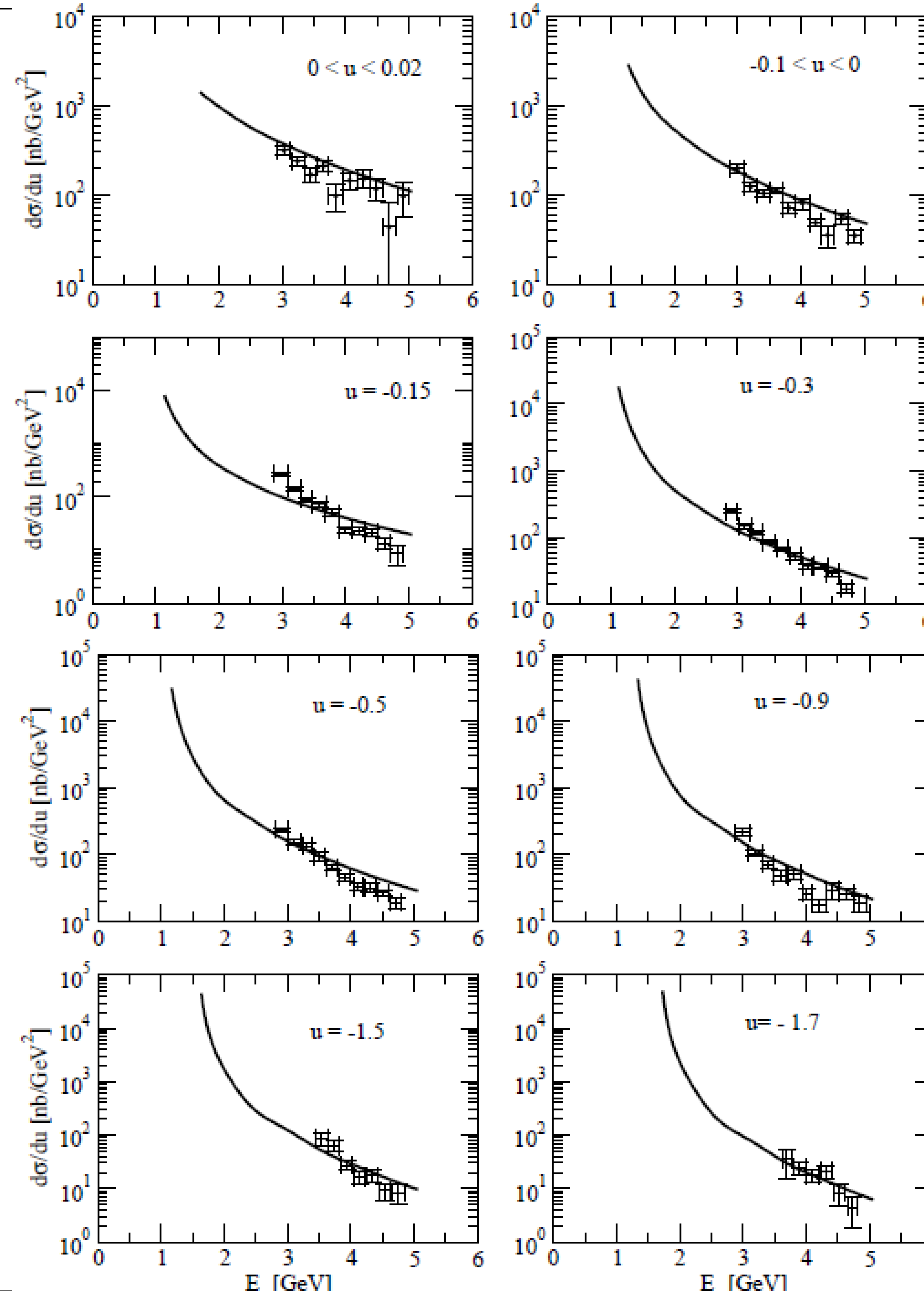
$a = 115, \quad b = -60 \quad \text{for } E_\gamma = 4.7\ \text{GeV}$

$\phi \sim \pi/2$ at $u = -0.15\ \text{GeV}^2$

- $\dfrac{d\sigma}{du}$ dependence on energy

▶ Relative phase fixed by

$a = 100, \quad b = 60$ for $E_\gamma = 3.5$ GeV



Summary and Outlooks

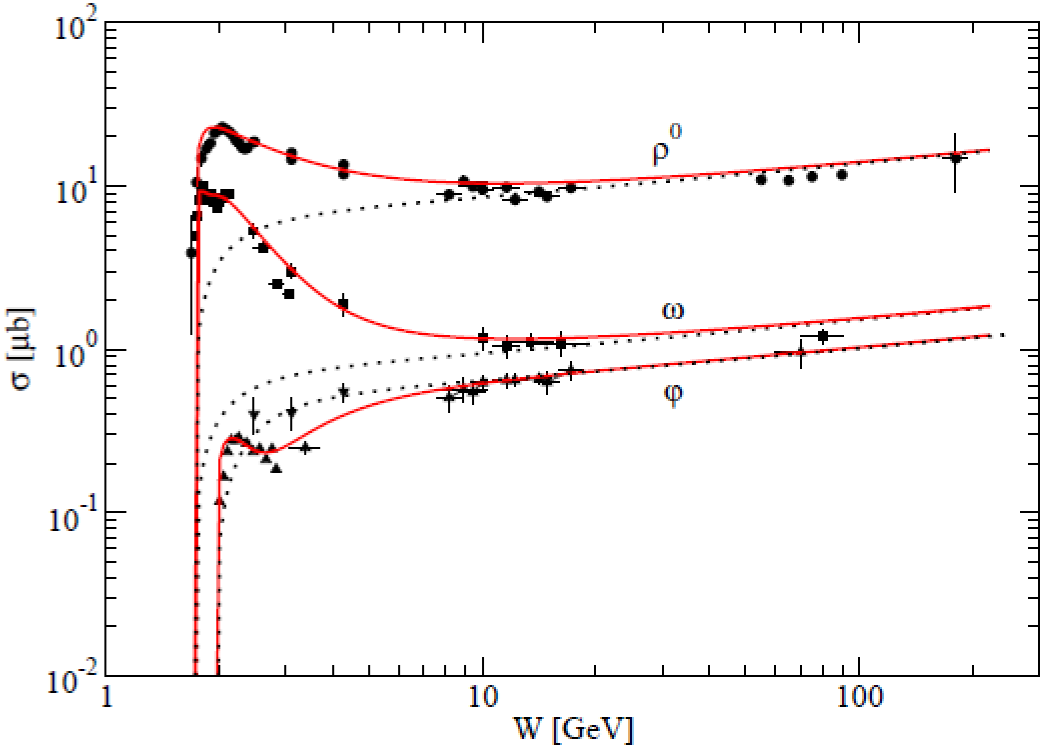
- We studied $\gamma N \to \omega N$ in Reggeized models at forward and backward angles for a comprehensive understanding of the reaction over the resonance region.
- Role of π with π-cuts introduced as a absorption mechanism are crucial to describe the reaction at forward angles and analyze scaling of cross sections with nonlinear trajectories for saturation at wide angles.
- Possibility of parton contrib. is investigated as a fill-up mechanism of the dip from nucleon Regge pole with nucleon isoscalar form factor at backward angles.
- It is desirable to measure the ω photoproduction in intermediate energy to explore those findings in the scaling and possibility of parton contributions.

Back up

Overall features of vector meson photoproductions

TABLE I. Physical constants in lighter vector meson photoproductions ρ^0, ω, and ϕ.

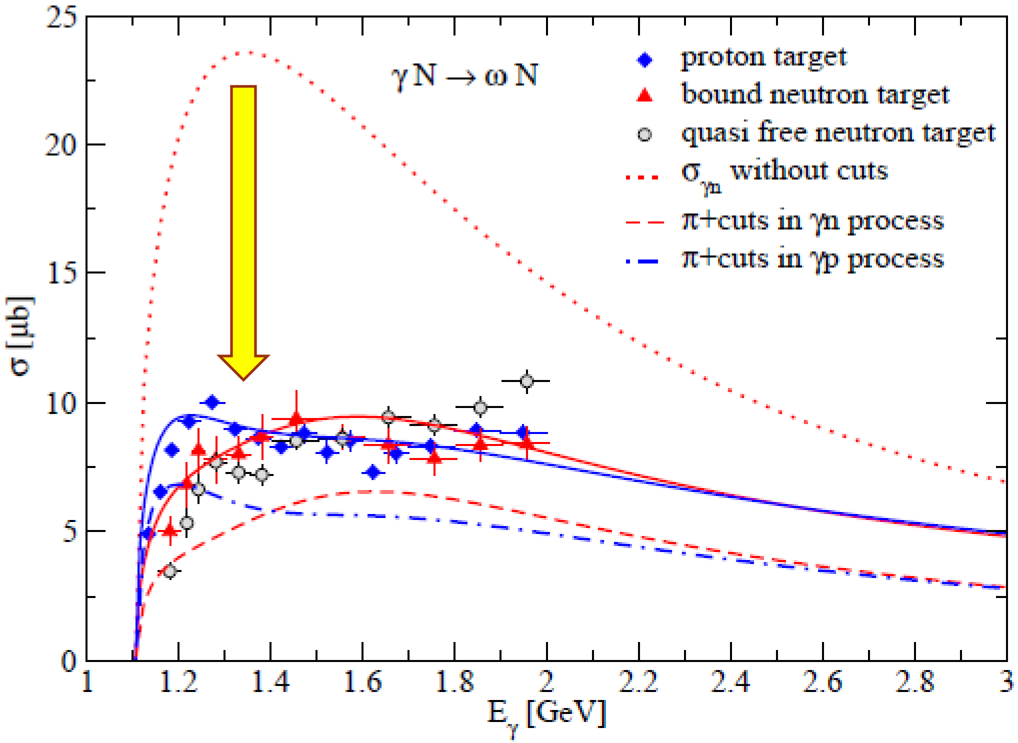
	ρ^0	ω	ϕ
$g_{V\pi\gamma}$	0.254	−0.69	0.065
$g_{\pi NN}$	13.4	13.4	13.4
$g_{V\sigma\gamma}$	−0.235	−0.17	−0.085
$g_{\sigma NN}$	14.6	14.6	14.6
g_{VNN}	2.6	15.6	3.4



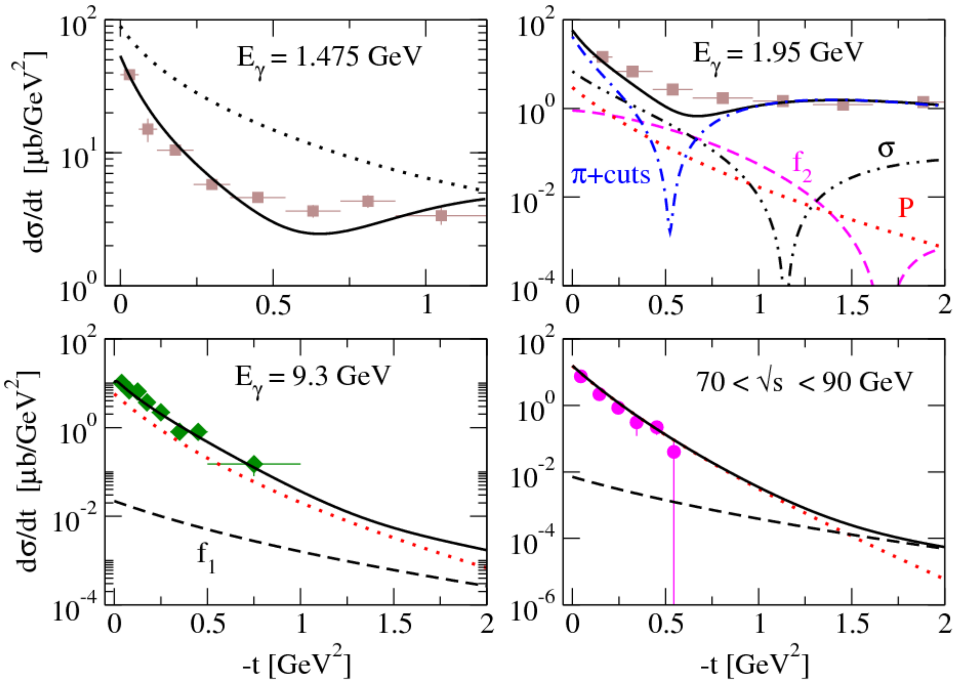
Regge cuts for γp and γn total cross sections

- Cuts in total cross sections
- Agreements with σ and $d\sigma/d\cos\theta$

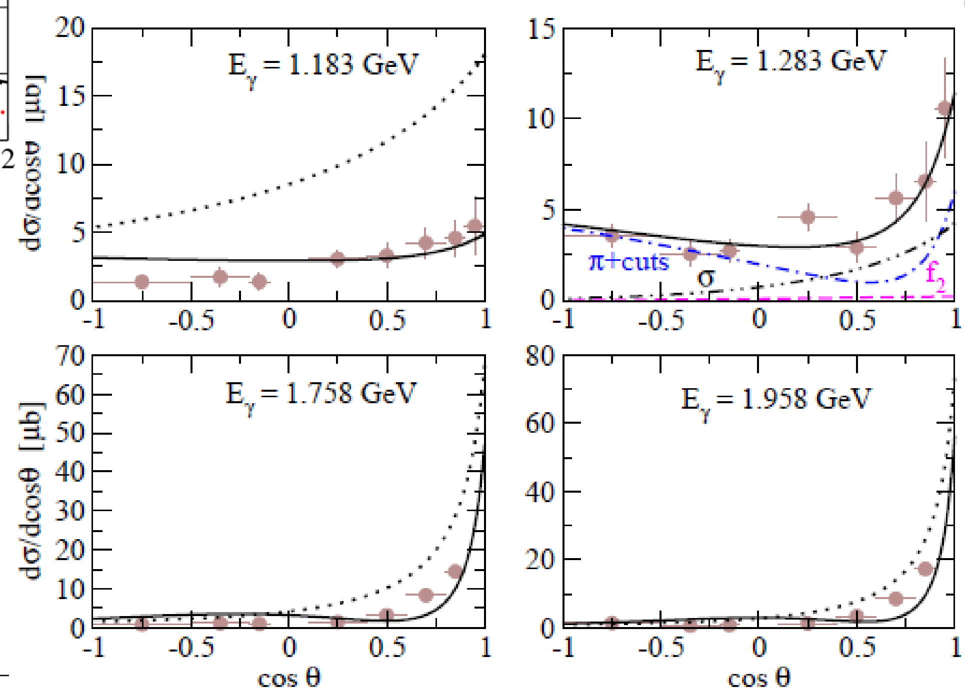
F. Dietz CBELSA/TAPS Collaboration Eur. Phys. J. A (2015) **51**: 6



Differential cross sections for γp and γn reactions



- Agreements with σ and $d\sigma/d\cos\theta$
- Roles of $\pi + \sigma + f_2$ near threshold
- Roles of Pomeron$+ f_1$ at high energies

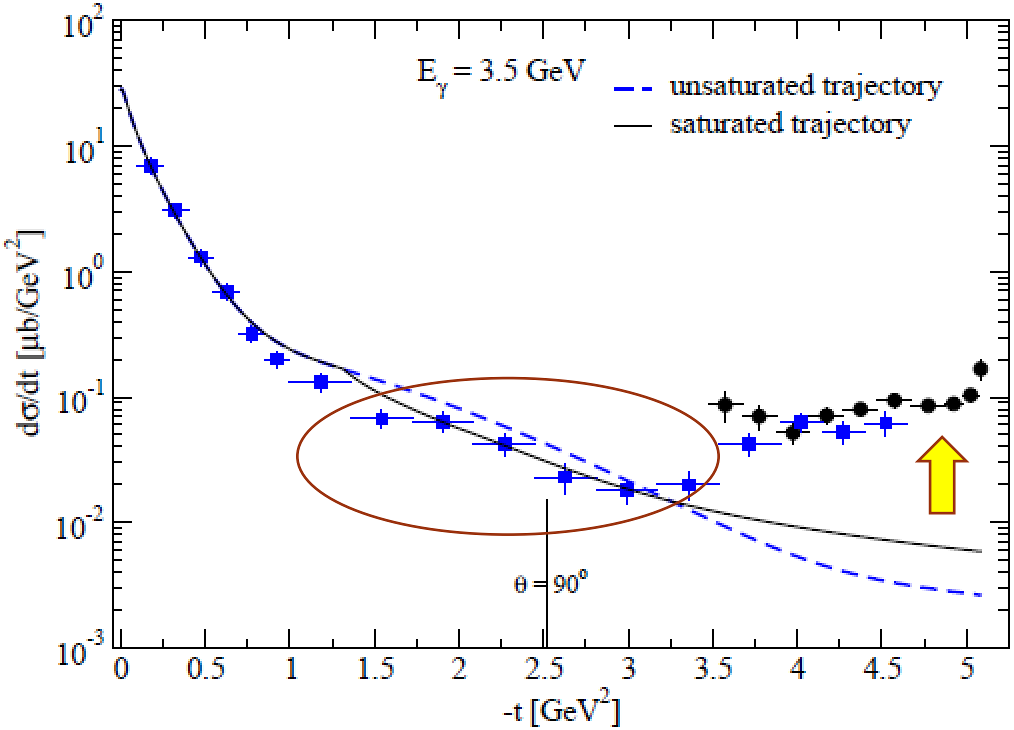


- $\Sigma \approx 0$ without N^*

$-t$ dependence of differential cross section

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

M. Battaglieri *et al.* (CLAS Collaboration), Phys. Rev. Lett. **90**, 022002-1 (2003)



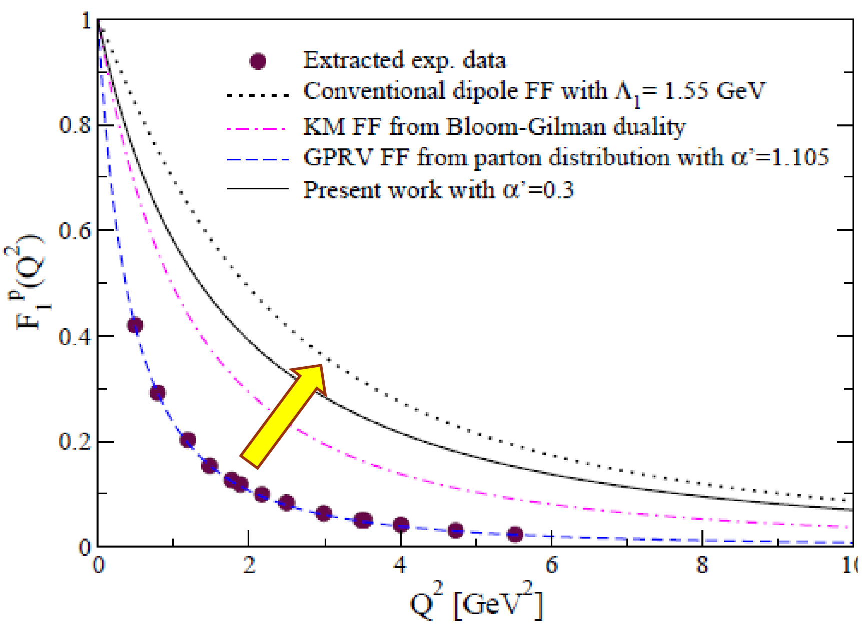
- Good fit at $\theta \approx 90^\circ$
- A limit to $t_{\text{max.}}$ without u-ch. exch.

On parameter α'

- **Proton charge FF in electroproduction of $p(e, e'\pi^+)n$**

  T. K. Choi, K.-J. Kong, B.-G. Yu, arXiv:1508.00969[nucl-th]

- **Data favors the dipole FF with $\Lambda = 1.55$ GeV**



$p(e, e'\pi^+)n$