Exclusive electroproduction of vector mesons

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2. $\gamma^{*}\, p \rightarrow \varphi(1020)\, p$

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Pomeron models & Application

Summary & Future work

Contents based on

[S.H.Kim, S.i.Nam, PRC.100.065208 (2019)]
[S.H.Kim, S.i.Nam, PRC.101.065201 (2020)]
[S.H.Kim, T.S.H.Lee, S.i.Nam, Y. Oh, PRC.104.045202 (2021)]

Introduction

◇ photoproduction ... electroproduction

$\gamma\, p \rightarrow (\varphi, \rho, \omega, J/\psi, \ldots)\, p$ ⇨ $\gamma^{*}\, p \rightarrow (\varphi, \rho, \omega, J/\psi, \ldots)\, p$

Regge model, at low W & Q^2

pQCD model, at high W & Q^2

production off nuclear targets

⇨ $\gamma^{(*)}\, A \rightarrow (\varphi, \rho, \omega, J/\psi, \ldots)\, A$, [A = ^{2}H, ^{4}He, ^{12}C,…]

distorted-wave impulse approximation

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distorted-wave impulse approximation

◇ These reactions are a rich source of information on soft and hard diffractive processes as well as the hadronic properties of the virtual photon.

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distorted-wave impulse approximation

◇ These reactions are a rich source of information on soft and hard diffractive processes as well as the hadronic properties of the virtual photon.

◇ Approved 12 GeV era experiments to date at Jafferson Labarotory:

[E12-09-003] Nucleon Resonances Studies with CLAS

[E12-11-002] Proton Recoil Polarization in the ${}^{4}He(e,e'p){}^{3}H$, ${}^{2}He(e,e'p)n$, ${}^{1}He(e,e'p)$

[E12-11-005] Meson spectroscopy with low Q^2 electron scattering in CLAS12

[E12-12-006] Near Threshold Electroproduction of J/ψ at 11 GeV

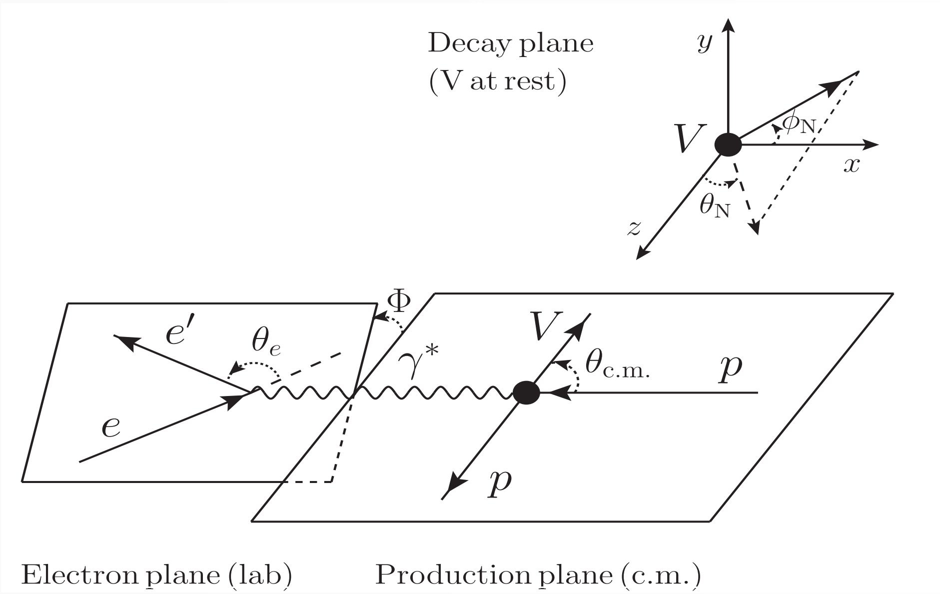
[E12-12-007] Exclusive Phi Meson Electroproduction with CLAS12

◇ Electron-Ion Collider (EIC) will carry out the relevant experiments in the future.

Exclusive electroproduction of vector mesons

$\gamma^{(*)}\, p \rightarrow V\, p$

reaction
plane



□ Photon(γ) polarization vector
Transverse comp. ($\lambda_\gamma=\pm1$) [photo-, electro-]
Longitudinal comp. ($\lambda_\gamma=0$) [electro-]

→ spin-density matrices (ρ_{ij}) [photo-, electro-]
→ decay angular distributions (W) [photo-, electro-]

→ σ, $d\sigma/d\Omega$, $d\sigma/dt$ [photo-, electro-]

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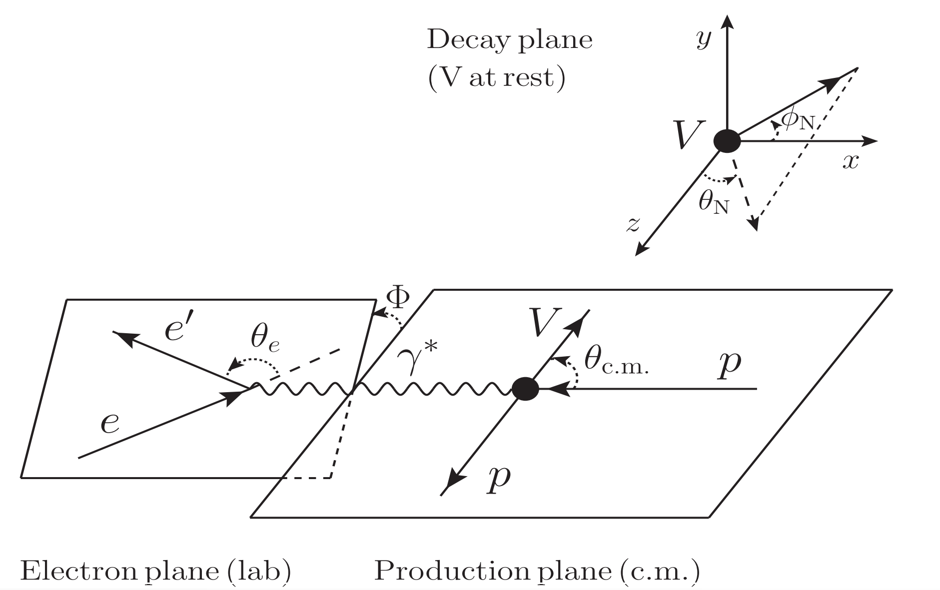

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→ σ, dσ/dΩ, dσ/dt [photo-, electro-]
→ σ_T, σ_L, σ_{TT}, σ_{LT}, $R=\sigma_L/\sigma_T$ … [electro-]
(T-L separated cross sections)

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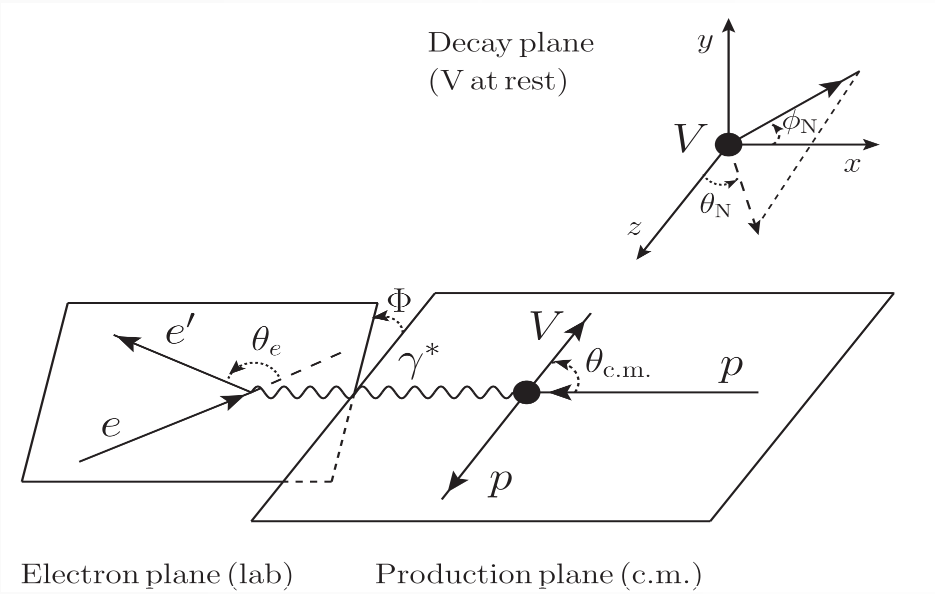

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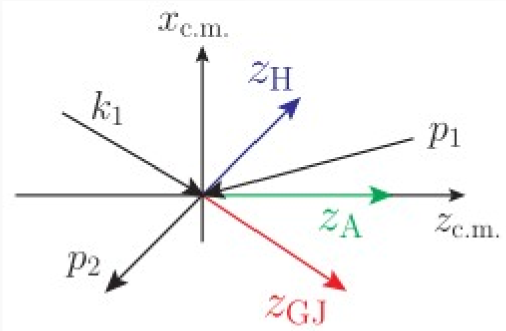
(T-L separated cross sections)

❑ Decay frame



Adair frame

Helicty frame: in favor of s-channel helicity conservation (SCHC)

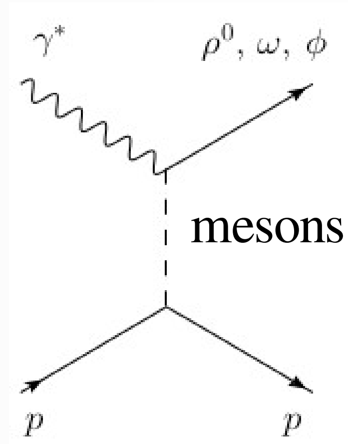
Gottfried-Jackson frame: in favor of t-channel helicity conservation (TCHC)

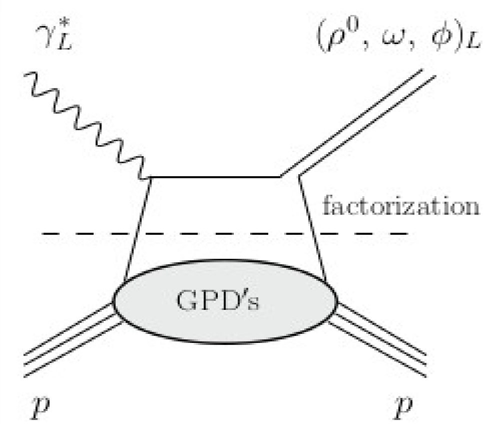
Exclusive electroproduction of vector mesons

$\gamma^* p \rightarrow V(\rho, \omega, \varphi, J/\psi)\ p$

theoretical framework

Q^2=0 <---> low Q^2	<<----->>	high Q^2





t-channel Regge trajectory exchange	<<----->>	handbag diagram

Exclusive electroproduction of vector mesons

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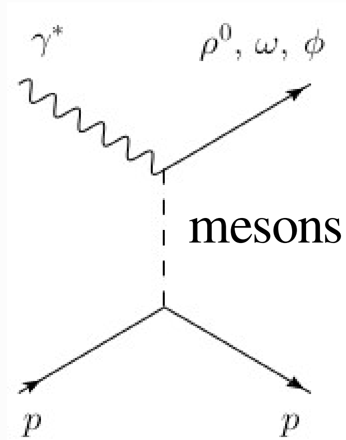
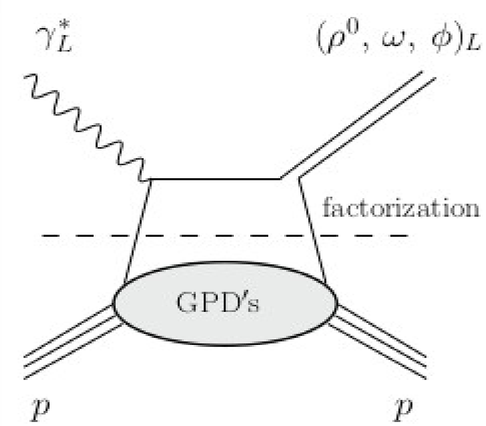




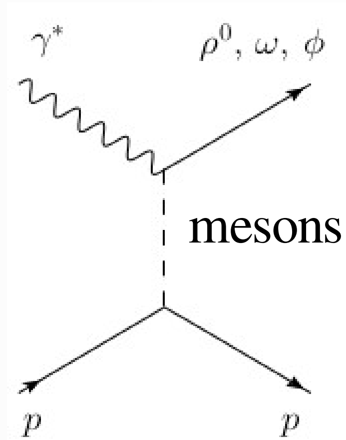
t-channel Regge trajectory exchange <<----->> handbag diagram

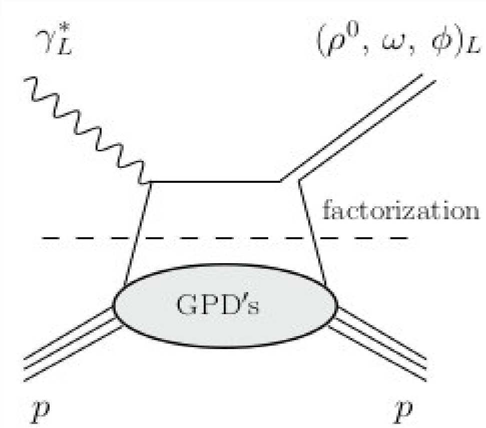
- Extending to "the virtual-photon sector" opens the way
  > to tune hadronic component of the exchanged photon
  > to explore to what extent meson exchange survives
  > to observe hard-scattering mechanisms,
  with a second hard scale, "photon virtuality $-(k_e-k_{e'})^2=Q^2$".

$\gamma^* p \rightarrow V(\rho, \omega, \varphi, J/\psi)\ p$

theoretical framework

$Q^2=0$ <---> low Q^2	<<----->>	high Q^2





t-channel Regge trajectory exchange	<<----->>	handbag diagram

JML Regge model

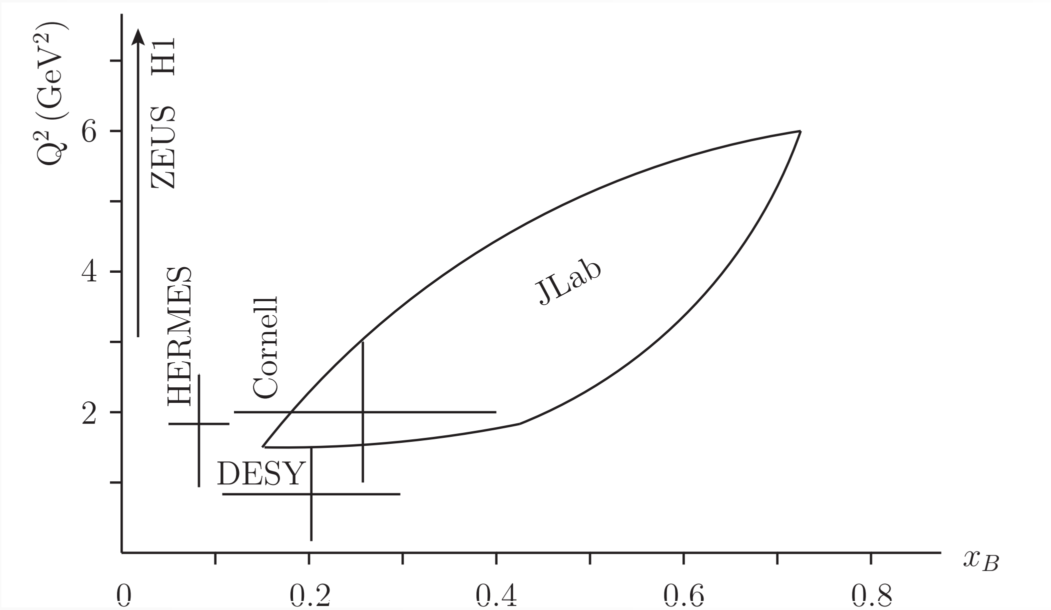
PLB.489.313 (2000)
PRD.70.054023 (2004)

VGG GPD-based model

PRL.80.5064 (1998)
PRD.60.094017 (1999)

Exclusive electroproduction of vector mesons

$\gamma^* p \rightarrow V(\rho, \omega, \varphi, J/\psi)\, p$



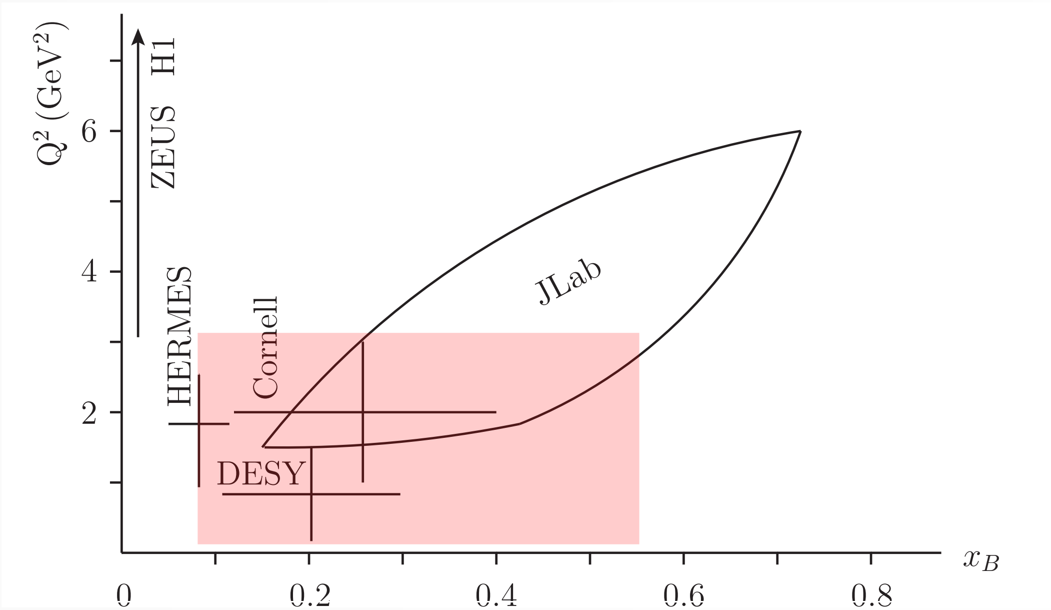
$$x_{\mathrm{Bj}} = \frac{Q^2}{W^2 + Q^2 - m^2}$$

[Kinematical range covered by vector meson electoproduction experiments]

❑ We can test which of the two descriptions - with “hadronic” or “quark” degrees of freedom - applies in the considered kinematical domain.

Exclusive electroproduction of vector mesons

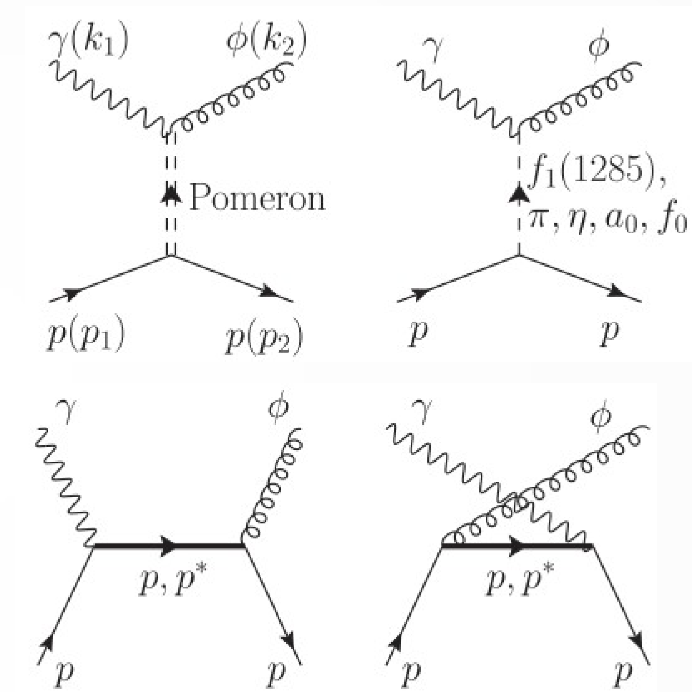
$\gamma^* p \rightarrow V(\rho, \omega, \varphi, J/\psi)\, p$



$$x_{\mathrm{Bj}} = \frac{Q^2}{W^2 + Q^2 - m^2}$$

[Kinematical range covered by vector meson electoproduction experiments]

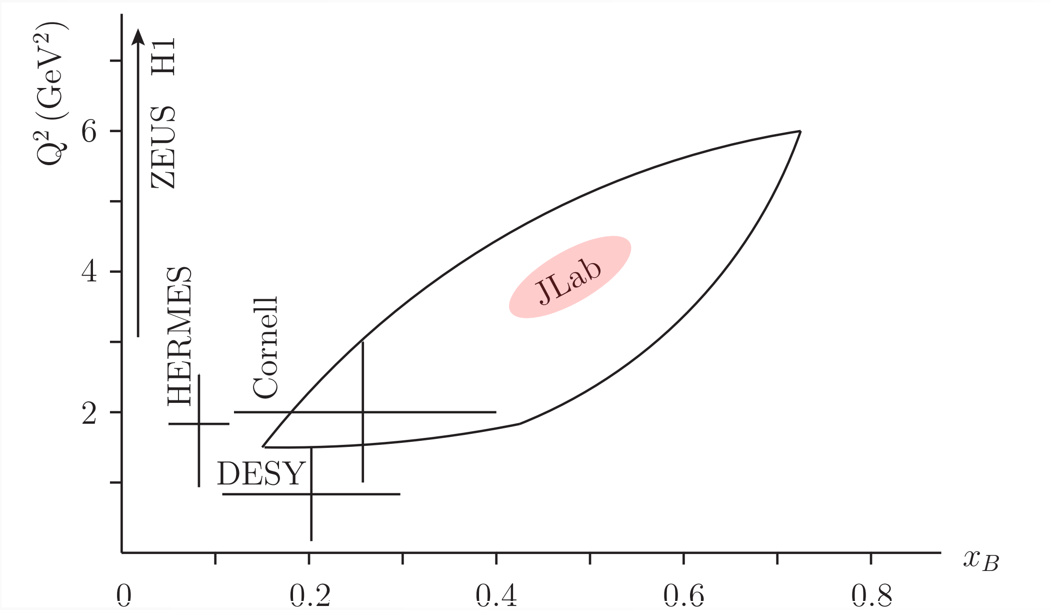
Feynman diagrams



- ❑ We can test which of the two descriptions - with "hadronic" or "quark" degrees of freedom - applies in the considered kinematical domain.
- ❑ At low photon virtualities ($Q^2 \lesssim M_V^2$) and low energies ($W \lesssim$ several GeV), our hadronic effective model is applicable.

Exclusive electroproduction of vector mesons

$\gamma^* p \rightarrow V(\rho, \omega, \varphi, J/\psi)\, p$



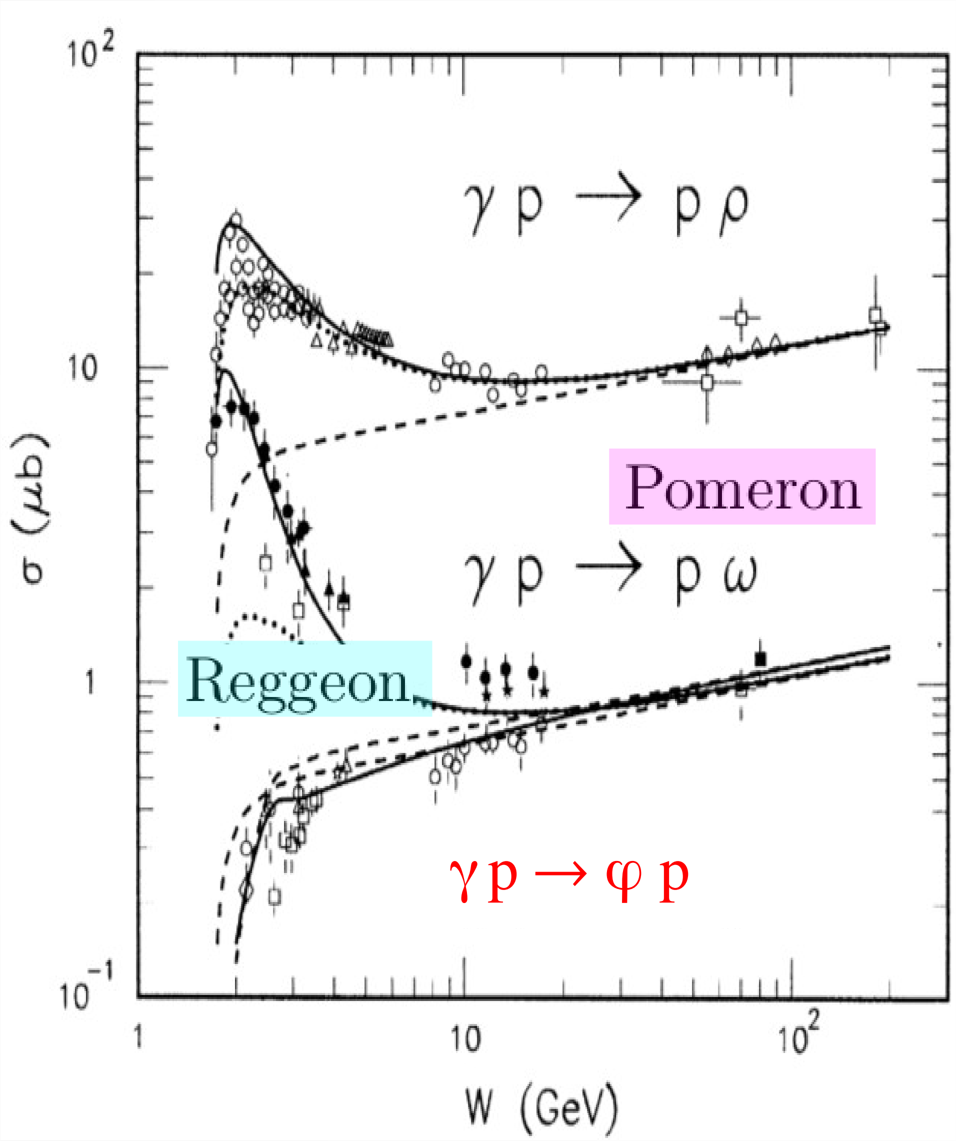
$$x_{\mathrm{Bj}} = \frac{Q^2}{W^2 + Q^2 - m^2}$$

[Kinematical range covered by vector meson electoproduction experiments]

- ❑ The upcoming data from Jefferson Laboratory are particularly promising because they cover wide kinematical ranges of Q^2 and x_B and thus provide a unique opportunity to test the two models.

- ❑ Electron-Ion Collider (EIC) will carry out the relevant experiments in the future.

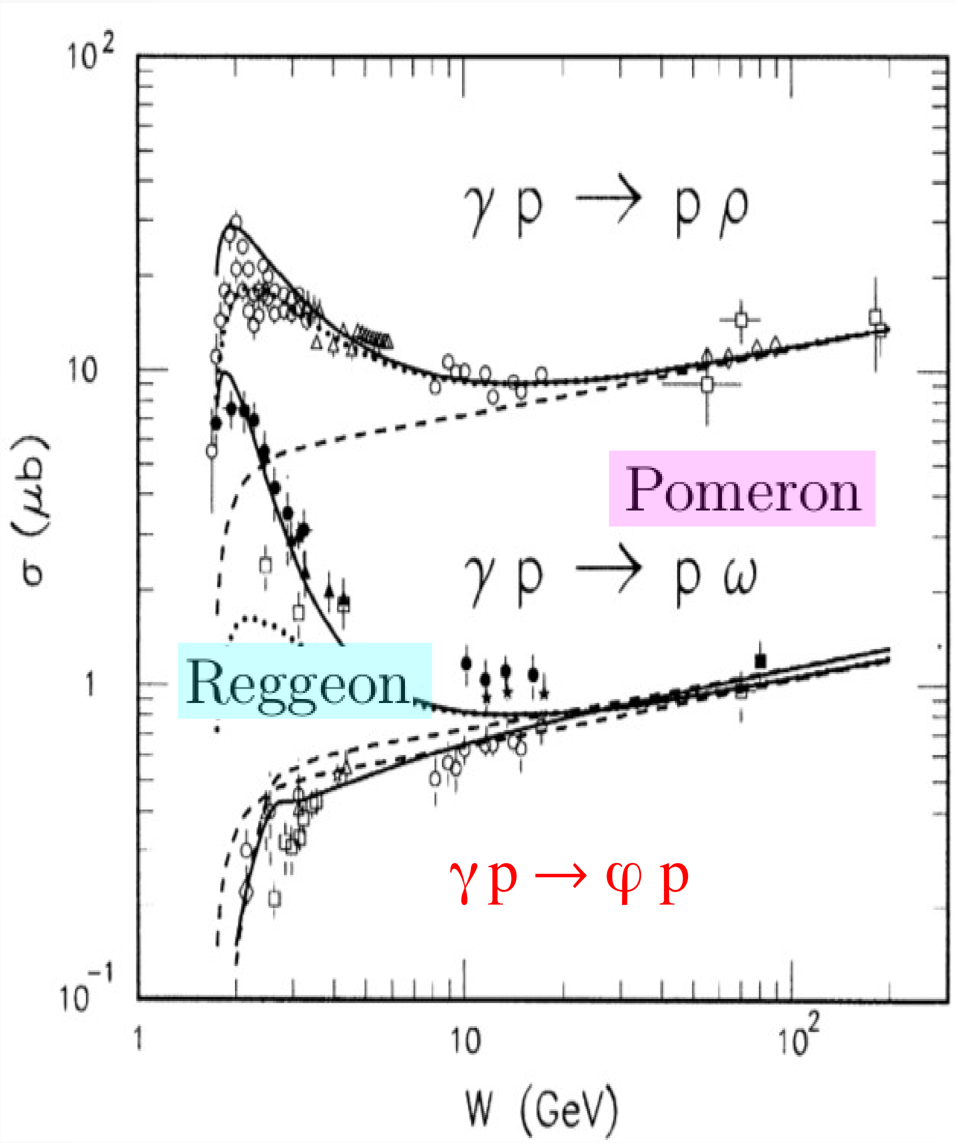
Exclusive photoproduction of vector mesons



- - - - Pomeron
• • • • Pomeron + f_2
—— total

[Laget, PLB.489.313 (2000)]

Exclusive photoproduction of vector mesons



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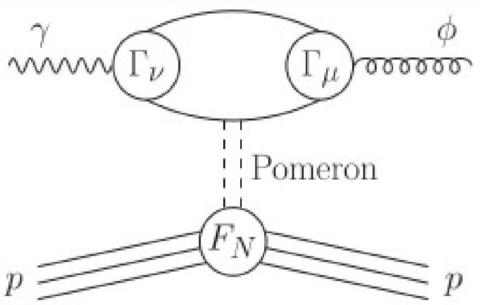
[Laget, PLB.489.313 (2000)]

❑ We focus on γ p → φ p.

❑ high energy

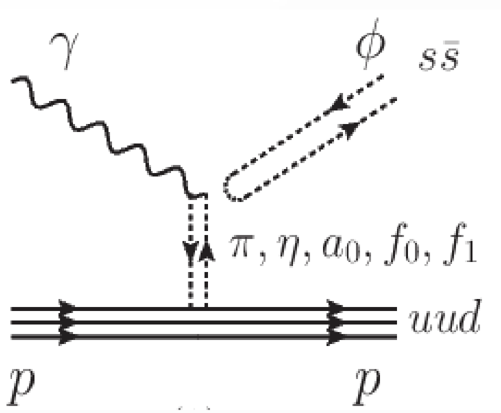


□ σ [γp → φp] ≈ σ [γp → ωp]

□ F_N: isoscalar EM form factor of the nucleon

$$F_N(t) = \frac{4M_N^2 - a_N^2 t}{(4M_N^2 - t)(1 - t/t_0)^2}$$

❑ low energy



□ σ[γp → φp] << σ[γp → (ρ,ω)p] due to the OZI rule

Exclusive photoproduction of vector mesons

❑ high energy:

The two-gluon exchange is simplified by the Donnachie-Landshoff (DL) model which suggests that the Pomeron couples to the nucleon like a C = +1 isoscalar photon and its coupling is described in terms of $F_N(t)$.

[Pomeron Physics and QCD (Cambridge University, 2002)]

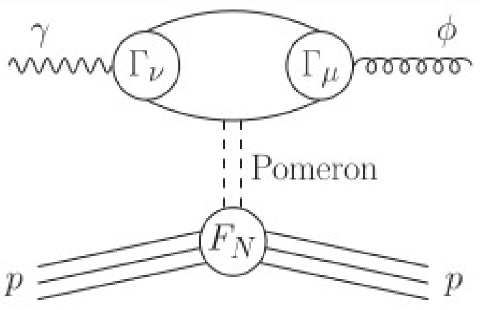
❑ low energy:

We need to clarify the reaction mechanism.

[Exp: CLAS, Dey, PRC.89. 055208 (2014)
CLAS, Seraydaryan, PRC.89.055206 (2014)
LEPS, Mizutani, PRC.96.062201 (2017)]

❑ We focus on γ p → φ p.

❑ high energy



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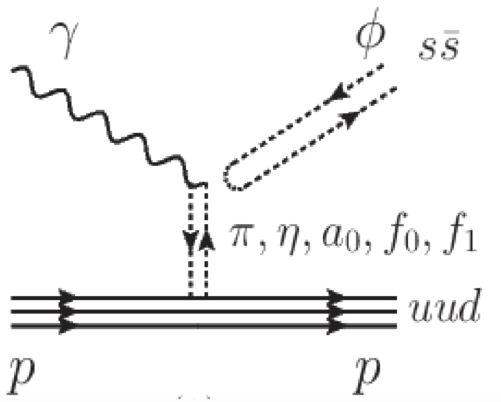
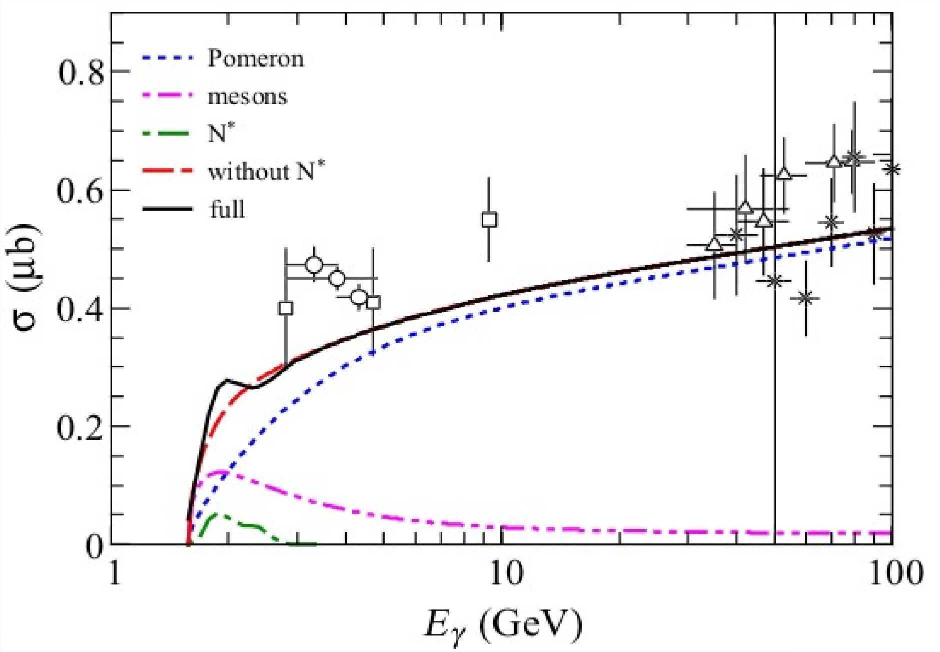


□ σ[γp → φp] << σ[γp → (ρ,ω)p] due to the OZI rule

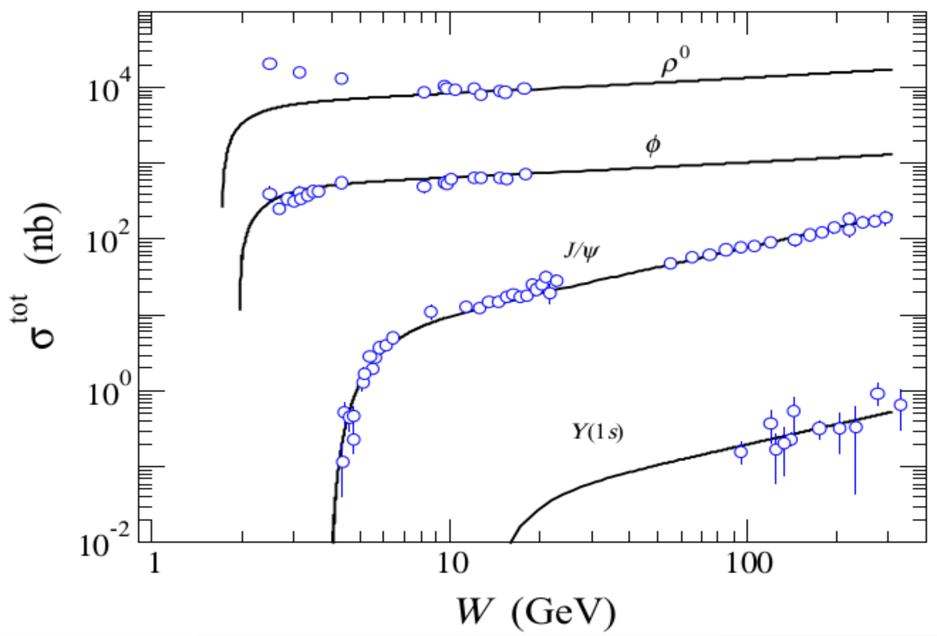
Exclusive photoproduction of vector mesons [results]

Born term total cross section

$\gamma\, p \to \varphi\, p$

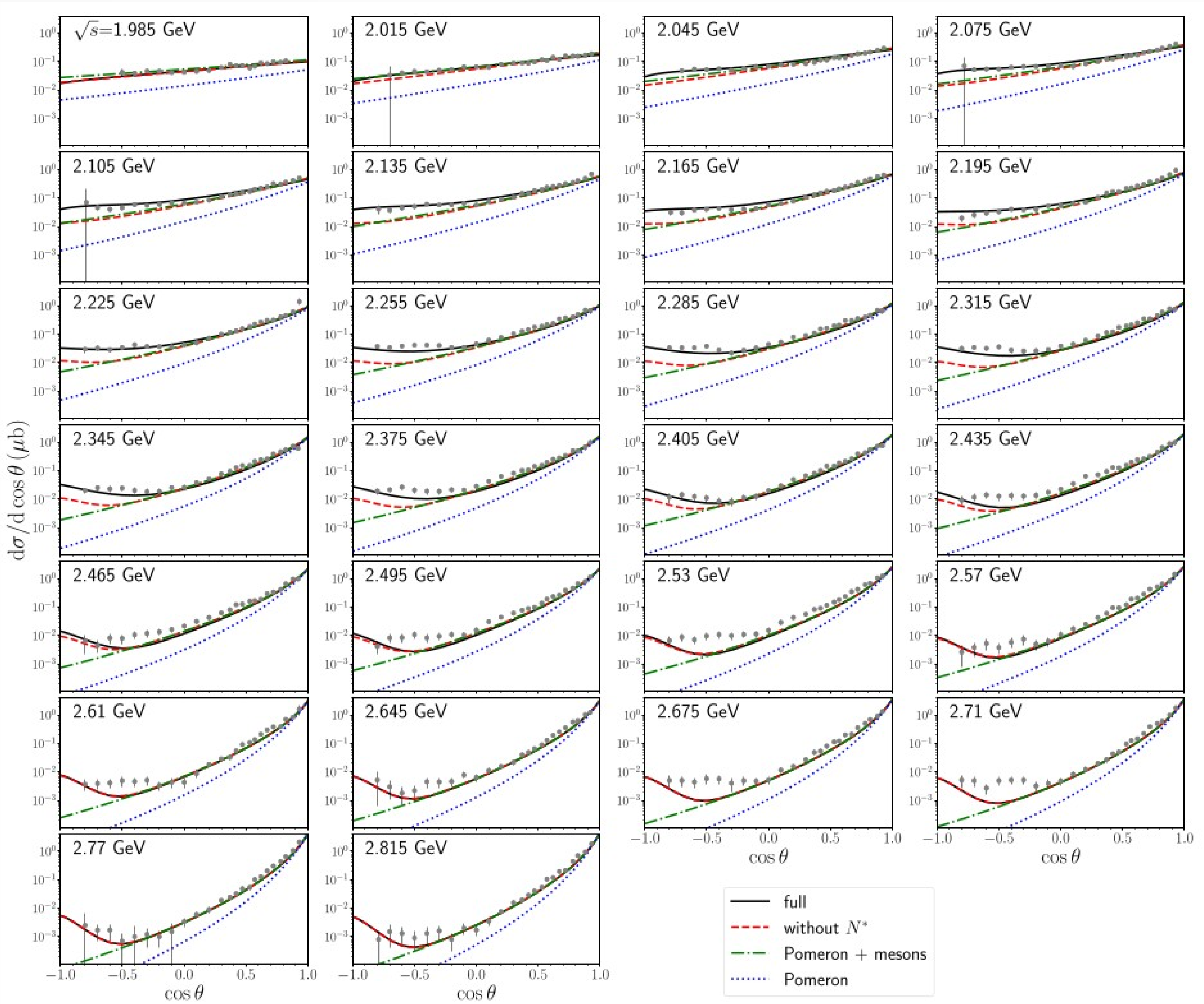


$\gamma\, p \to \rho^0, \omega, \varphi, J/\psi, \Upsilon(1s)$



□ Our Pomeron model describes the high energy regions quite well.

Exclusive photoproduction of vector mesons [results]



differential cross sections
[$\gamma\, p \to \varphi\, p$]

Born term

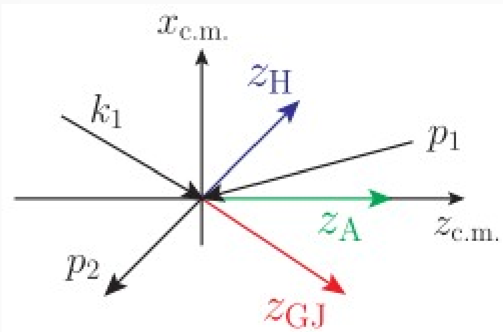
- □ Forward: Pomeron exchange
- □ Backward: mesons, nucleon, N^* exchanges

play crucial roles.

[Exp: CLAS, Dey, PRC.89. 055208 (2014)]

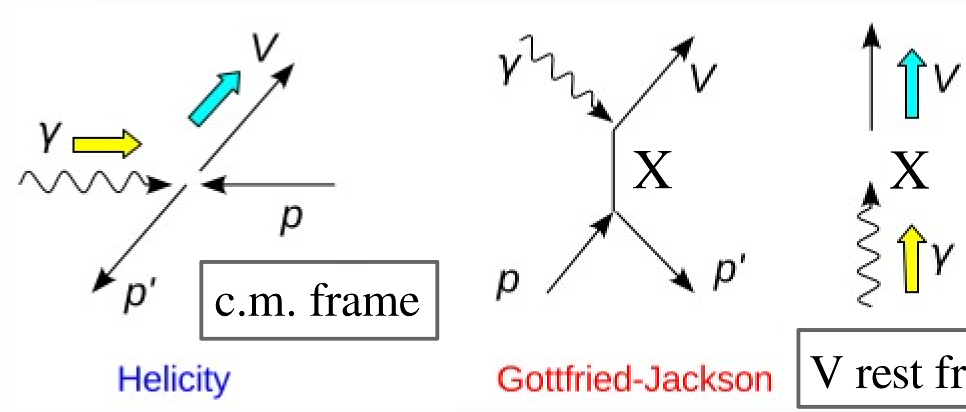
spin-density matrices

❑ Decay frame



V rest frame

Adair frame
Helicity frame
Gottfried-Jackson frame



Definition

$$\rho^0_{\lambda\lambda'} = \frac{1}{N} \sum_{\lambda_\gamma, \lambda_i, \lambda_f} \mathcal{M}_{\lambda_f \lambda; \lambda_i \lambda_\gamma} \mathcal{M}^*_{\lambda_f \lambda'; \lambda_i \lambda_\gamma},$$

$$\rho^1_{\lambda\lambda'} = \frac{1}{N} \sum_{\lambda_\gamma, \lambda_i, \lambda_f} \mathcal{M}_{\lambda_f \lambda; \lambda_i -\lambda_\gamma} \mathcal{M}^*_{\lambda_f \lambda'; \lambda_i \lambda_\gamma},$$

$$\rho^2_{\lambda\lambda'} = \frac{i}{N} \sum_{\lambda_\gamma, \lambda_i, \lambda_f} \lambda_\gamma \mathcal{M}_{\lambda_f \lambda; \lambda_i -\lambda_\gamma} \mathcal{M}^*_{\lambda_f \lambda'; \lambda_i \lambda_\gamma},$$

$$\rho^3_{\lambda\lambda'} = \frac{1}{N} \sum_{\lambda_\gamma, \lambda_i, \lambda_f} \lambda_\gamma \mathcal{M}_{\lambda_f \lambda; \lambda_i \lambda_\gamma} \mathcal{M}^*_{\lambda_f \lambda'; \lambda_i \lambda_\gamma},$$

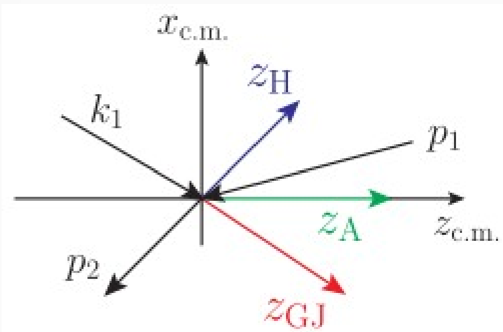
□ λ, λ' : Helicity states of the vector-meson

□ For a *t*-channel exchange of X,
the momentum of γ and V is collinear in the GJ frame.

Thus, the ρij^k elements measure the degree of helicity flip due to the *t*-channel exchange of X in the GJ frame.

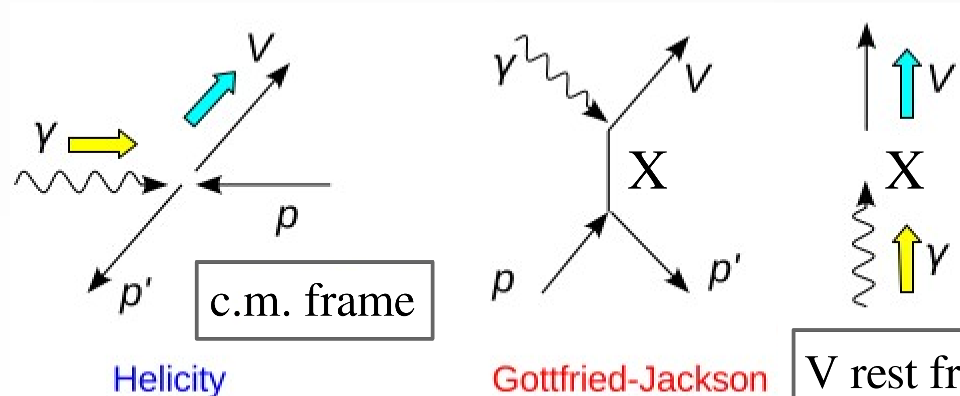
spin-density matrices

❑ Decay frame



V rest frame

Adair frame
Helicty frame
Gottfried-Jackson frame



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$$\rho^0_{00} \propto \left|\mathcal{M}_{\lambda_\gamma=1,\lambda_\phi=0}\right|^2 + \left|\mathcal{M}_{\lambda_\gamma=-1,\lambda_\phi=0}\right|^2$$

- Single helicity-flip transition between γ & V

$$-\mathrm{Im}[\rho^2_{1-1}] \approx \rho^1_{1-1} = \frac{1}{2}\frac{\sigma^N - \sigma^U}{\sigma^N + \sigma^U}$$

- Relative contribution between Natural & Unnatural parity exchanges

□ Convert into other frames by applying Wigner rotations:

$$\alpha_{\rm A\to H} = \theta_{\rm c.m.},$$

$$\alpha_{\rm H\to GJ} = -\cos^{-1}\left(\frac{v-\cos\theta_{\rm c.m.}}{v\cos\theta_{\rm c.m.}-1}\right)$$

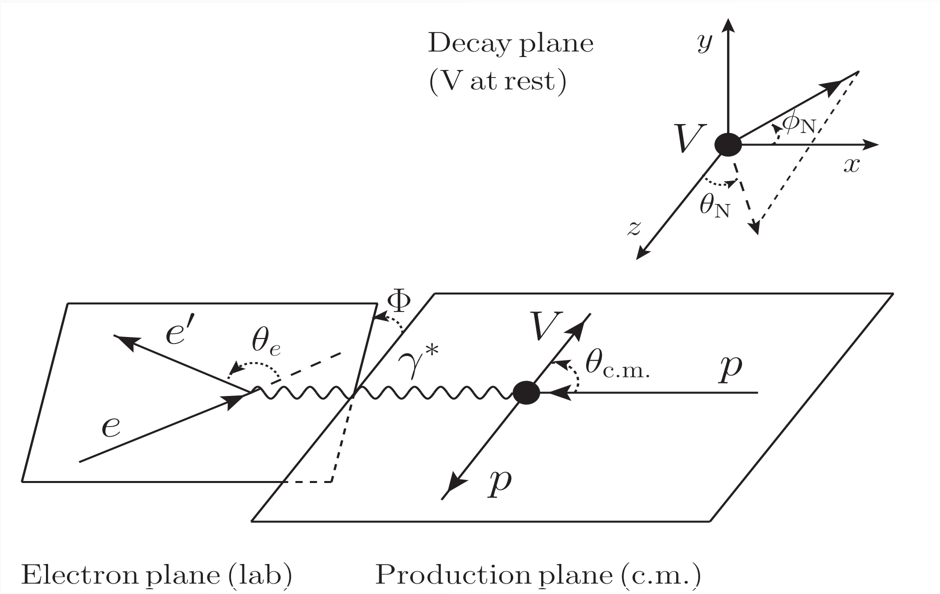
$$\alpha_{\rm A\to GJ} = \alpha_{\rm A\to H} + \alpha_{\rm H\to GJ}$$

v : The velocity of the K meson in the φ rest frame ($\varphi \to K\bar{K}$ decay)

Exclusive electroproduction of vector mesons

$\gamma^* p \rightarrow V p$

reaction plane



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(T-L separated cross sections)

Exclusive electroproduction of vector mesons

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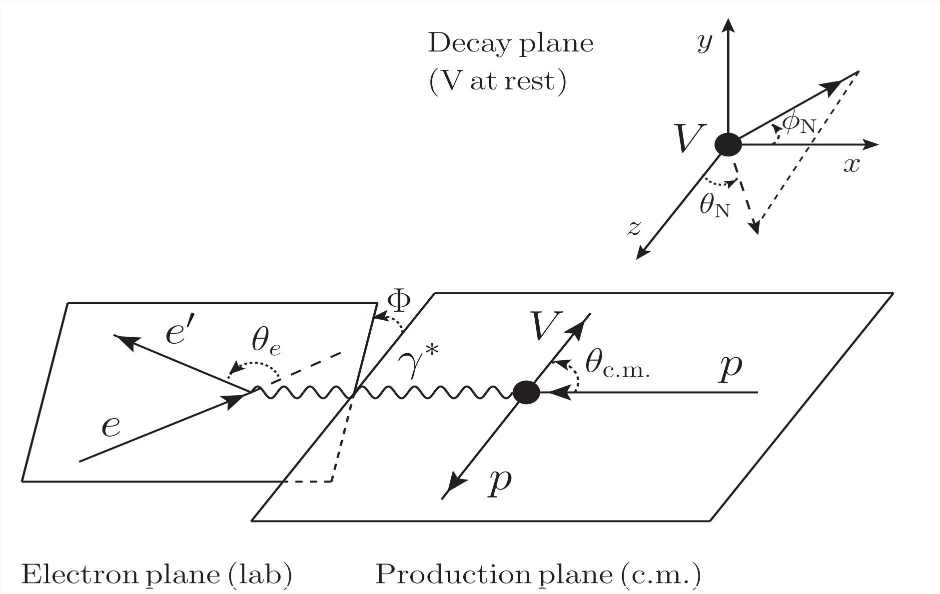

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(T-L separated cross sections)

total cross section

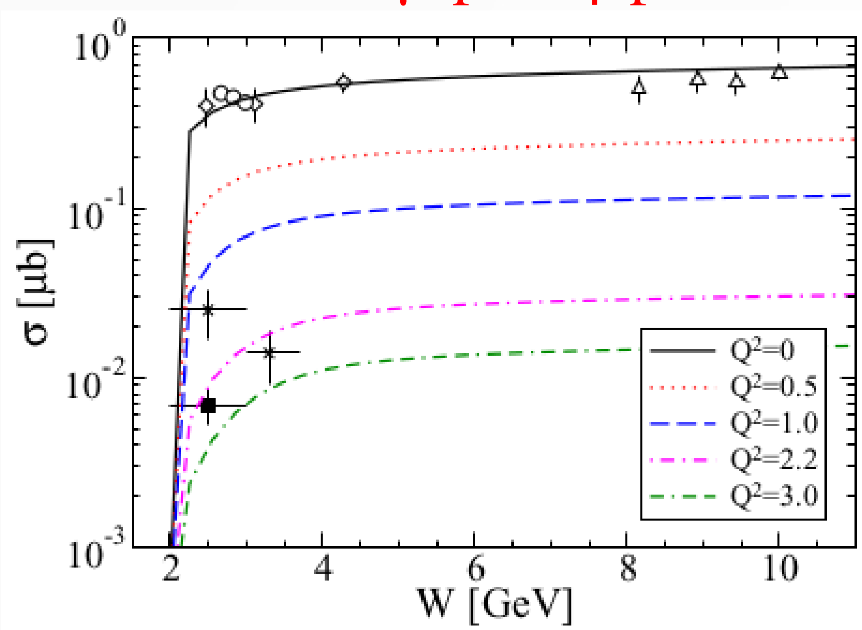
$$\sigma = \sigma_T + \varepsilon\sigma_L \qquad \frac{d\sigma}{d\Phi} = \frac{1}{2\pi}\left(\sigma + \varepsilon\sigma_{TT}\cos 2\Phi + \sqrt{2\varepsilon(1+\varepsilon)}\sigma_{LT}\cos\Phi\right)$$

ε: Virtual-photon polarization parameter

Exclusive electroproduction of vector mesons

unpolarized cross sections

a-1 $\gamma^* p \to \varphi\, p$

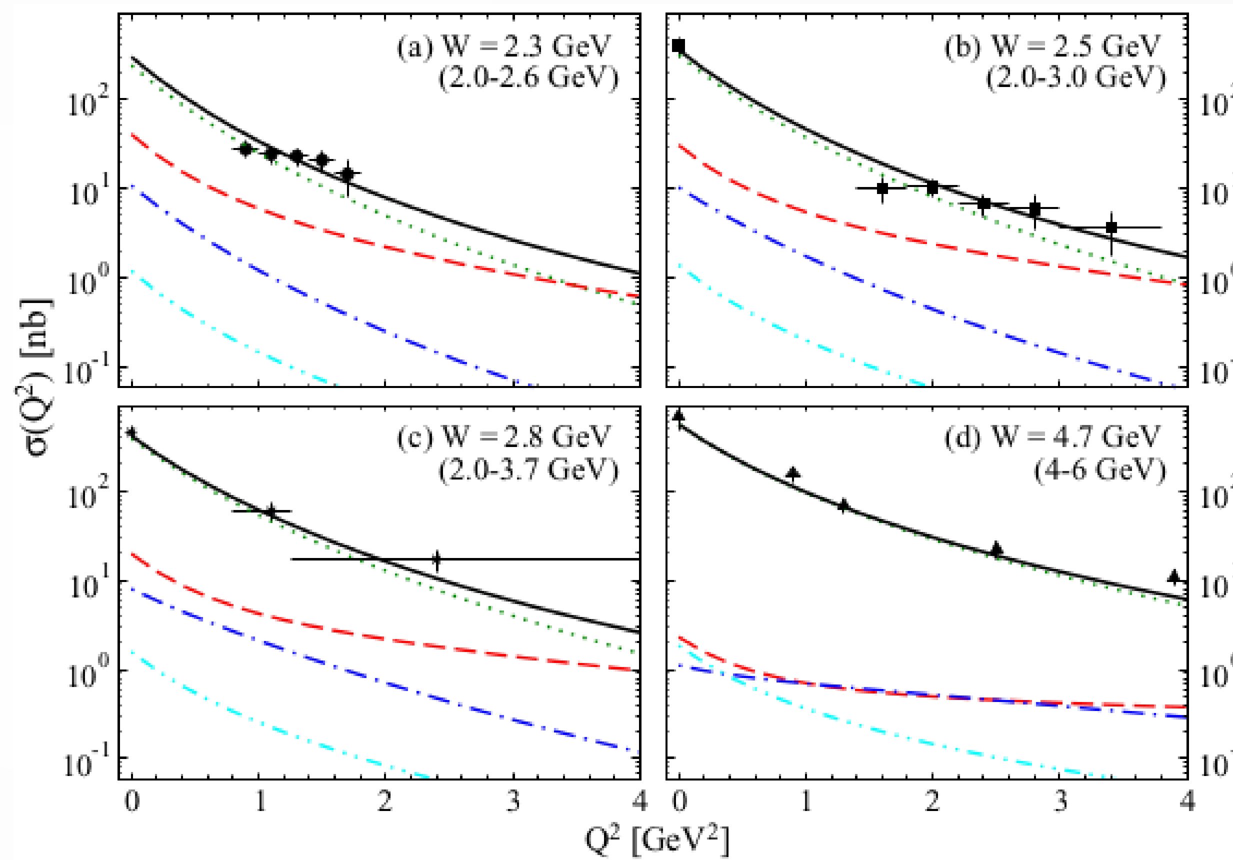


$$\sigma = \sigma_T + \varepsilon\sigma_L$$

$$\frac{d\sigma}{d\Phi} = \frac{1}{2\pi}\left(\sigma + \varepsilon\sigma_{TT}\cos 2\Phi + \sqrt{2\varepsilon(1+\varepsilon)}\sigma_{LT}\cos\Phi\right)$$

ε: Virtual-photon polarization parameter

Exp: [CLAS] PRC.63.065205 (2001), PRC.78.025210 (2008)
[Cornell] PRD.24.2787 (1981)
[HERMES] ActaPhys.Pol.B.31.2353 (2000)



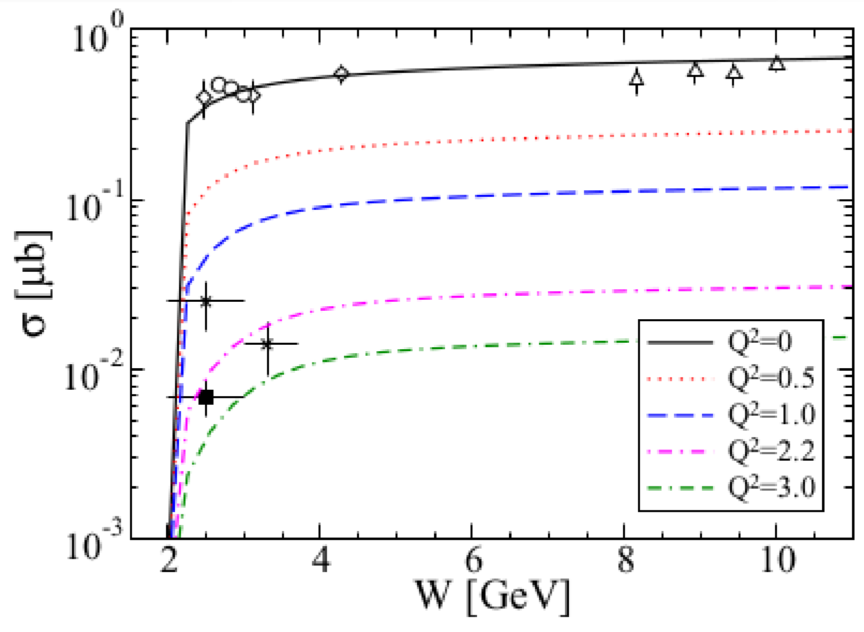
Pomeron | PS (π,η) | total | S (a_0,f_0) | AV (f_1)

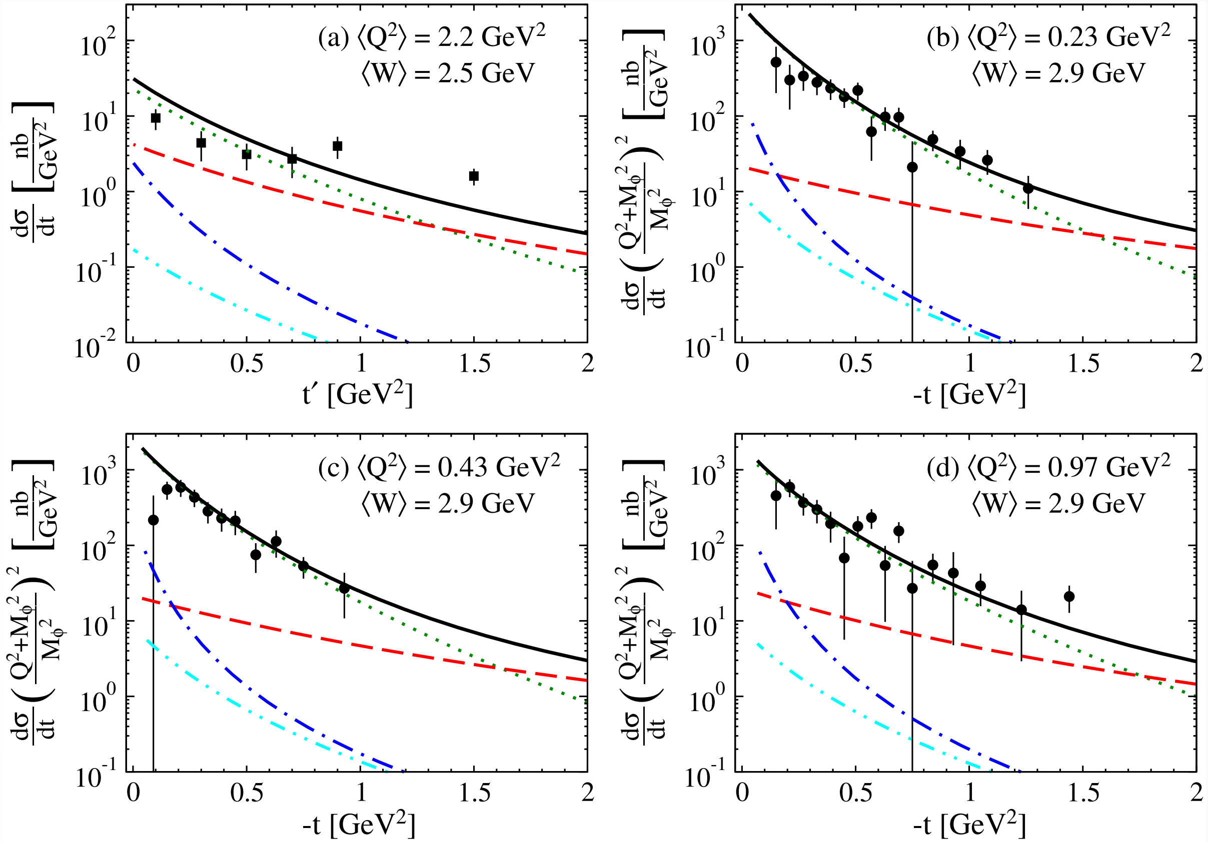
- □ The Q^2 dependence of the cross sections is well described.
- □ The agreement with the exp. data is good at the real photon limit Q^2=0.

unpolarized cross sections

Exp: [CLAS] PRC.78.025210 (2008)
[Cornell] PRL.39.516 (1977), PRD.19.3185 (1979)

a-2 $\gamma^* p \to \varphi p$





Pomeron | PS (π,η) | total
S (a0,f0) | AV (f1)

$$\sigma = \sigma_T + \varepsilon\sigma_L$$

$$\frac{d\sigma}{d\Phi} = \frac{1}{2\pi}\left(\sigma + \varepsilon\sigma_{TT}\cos 2\Phi + \sqrt{2\varepsilon(1+\varepsilon)}\sigma_{LT}\cos\Phi\right)$$

ε: Virtual-photon polarization parameter

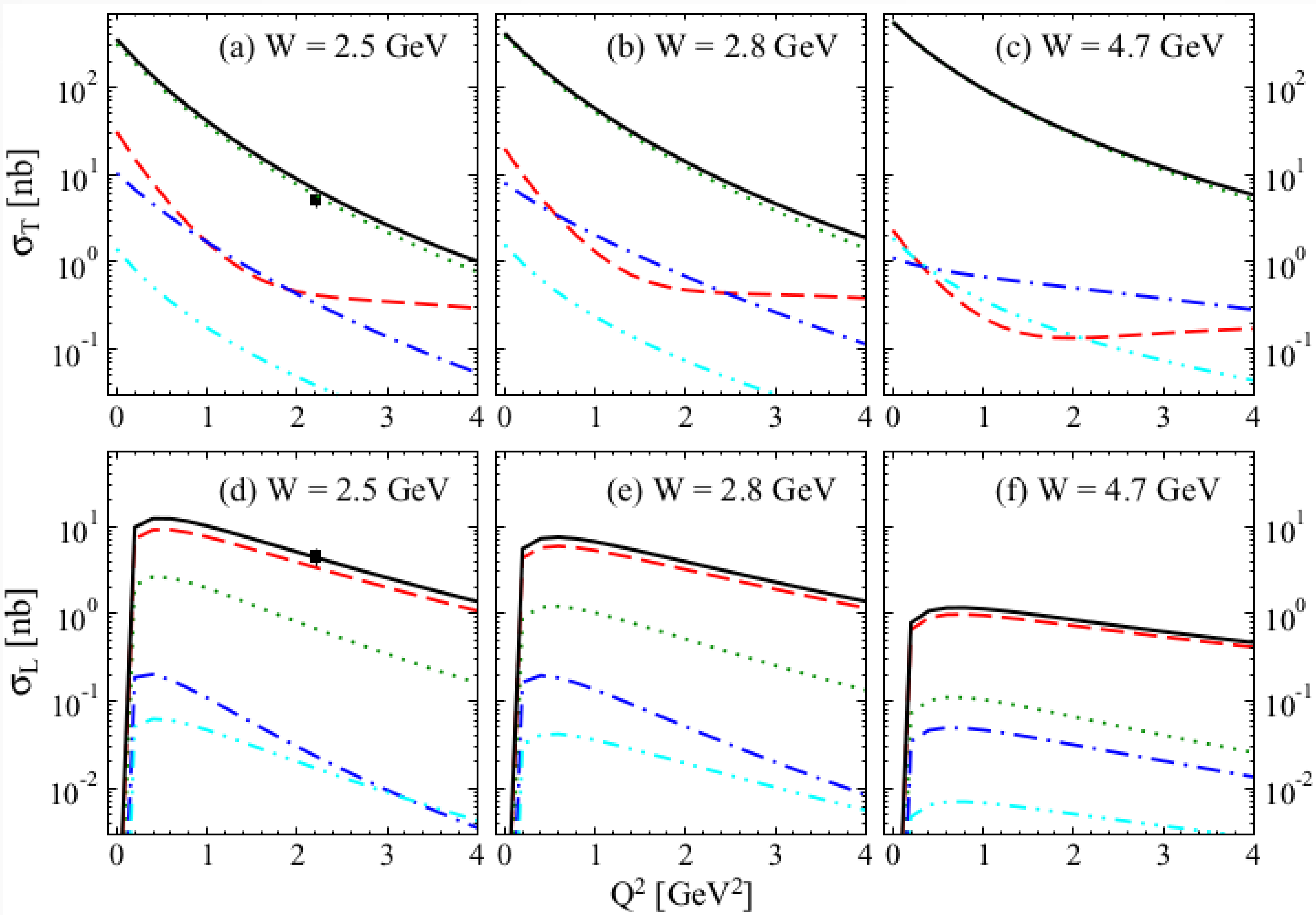
□ The Q^2 dependence of the cross sections is well described.

□ The agreement with the exp. data is good at the real photon limit Q^2=0.

Exclusive electroproduction of vector mesons

T-L separated cross sections at low W

a-3 $\gamma^* p \to \varphi p$



$$\frac{1}{\mathcal{N}}\frac{d\sigma_{\mathrm{T}}}{dt} = \frac{1}{2}\sum_{\lambda_\gamma=\pm1}\overline{|\mathcal{M}^{(\lambda_\gamma)}|^2},$$

$$\frac{1}{\mathcal{N}}\frac{d\sigma_{\mathrm{L}}}{dt} = \overline{|\mathcal{M}^{(\lambda_\gamma=0)}|^2},$$

$$\frac{1}{\mathcal{N}}\frac{d\sigma_{\mathrm{TT}}}{dt} = -\frac{1}{2}\sum_{\lambda_\gamma=\pm1}\overline{\mathcal{M}^{(\lambda_\gamma)}\mathcal{M}^{(-\lambda_\gamma)^*}},$$

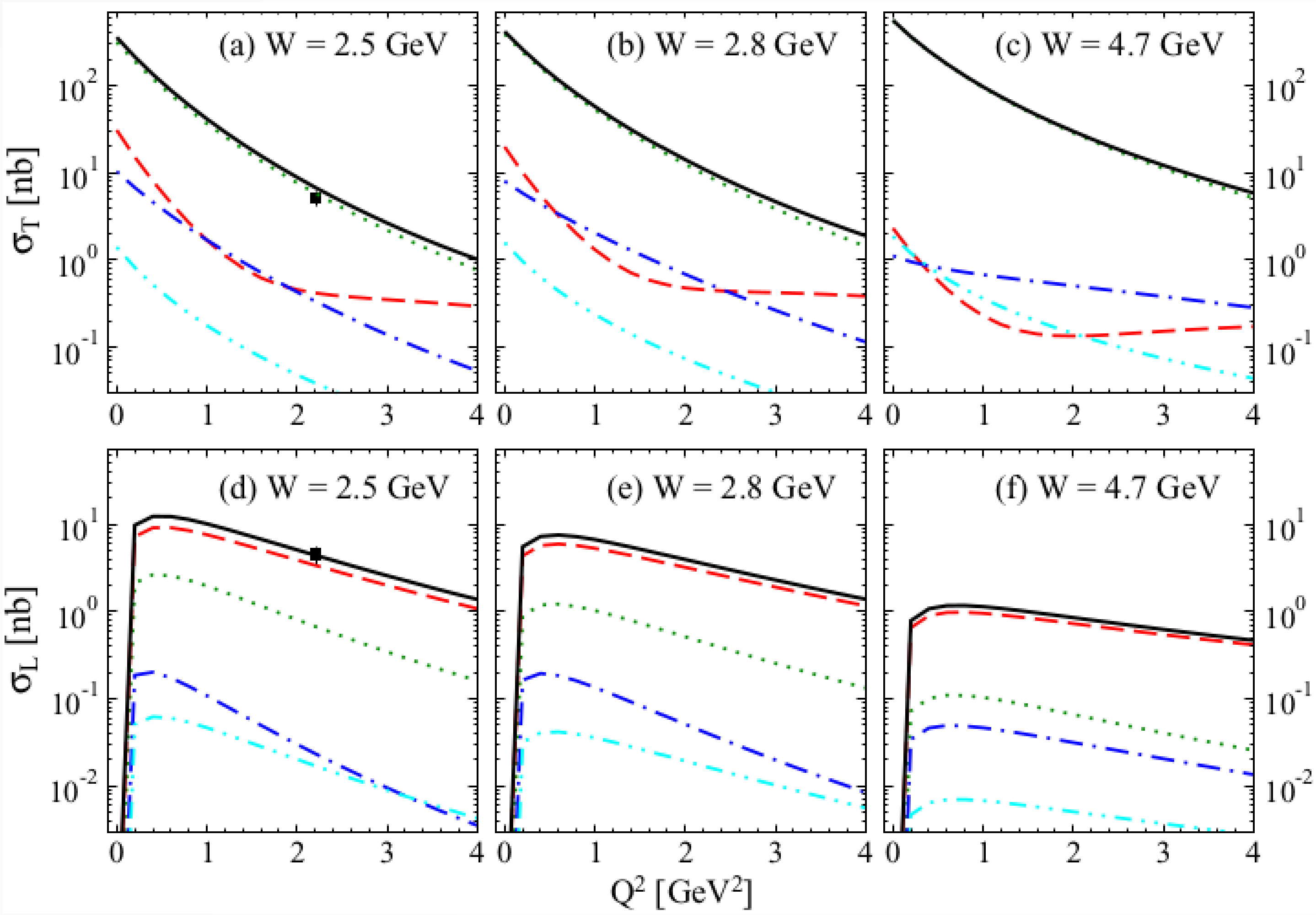
$$\frac{1}{\mathcal{N}}\frac{d\sigma_{\mathrm{LT}}}{dt} = -\frac{1}{2\sqrt{2}}\sum_{\lambda_\gamma=\pm1}\lambda_\gamma\left(\overline{\mathcal{M}^{(0)}\mathcal{M}^{(\lambda_\gamma)^*}} + \overline{\mathcal{M}^{(\lambda_\gamma)}\mathcal{M}^{(0)^*}}\right)$$

[Exp: CLAS, Santoro, PRC.78.025210 (2008)]

□ Pomeron and S-meson exchanges dominate transverse (T) and longitudinal (L) cross sections, respectively.

T-L separated cross sections at low W

a-3 $\gamma^* p \rightarrow \varphi p$



Pomeron

S (a_0, f_0)

PS (π, η)

AV (f_1)

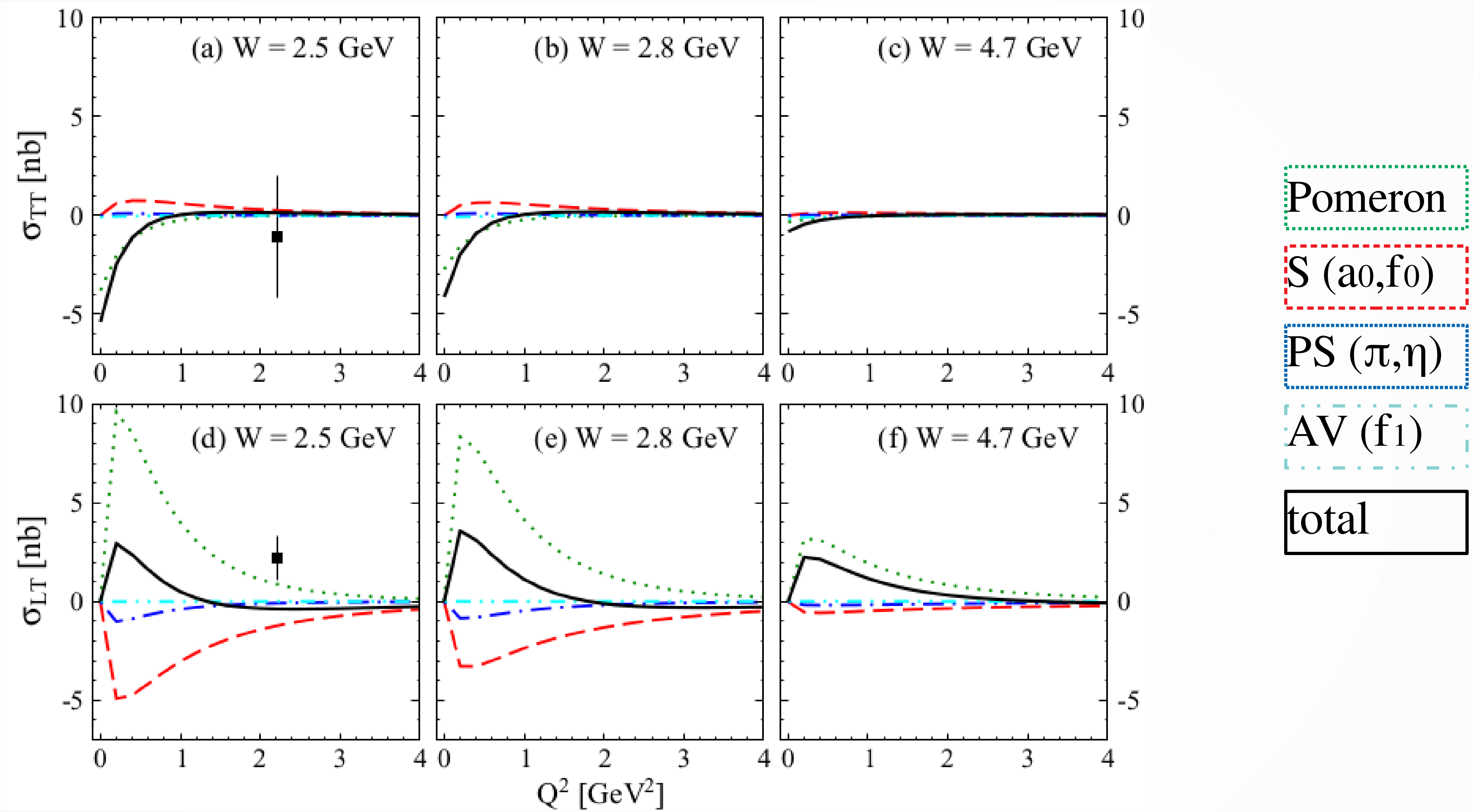
total

[Exp: CLAS, Santoro, PRC.78.025210 (2008)]

□ Pomeron and S-meson exchanges dominate transverse (T) and longitudinal (L) cross sections, respectively.

T-L separated cross sections at low W

a-4 $\gamma^* p \to \varphi p$

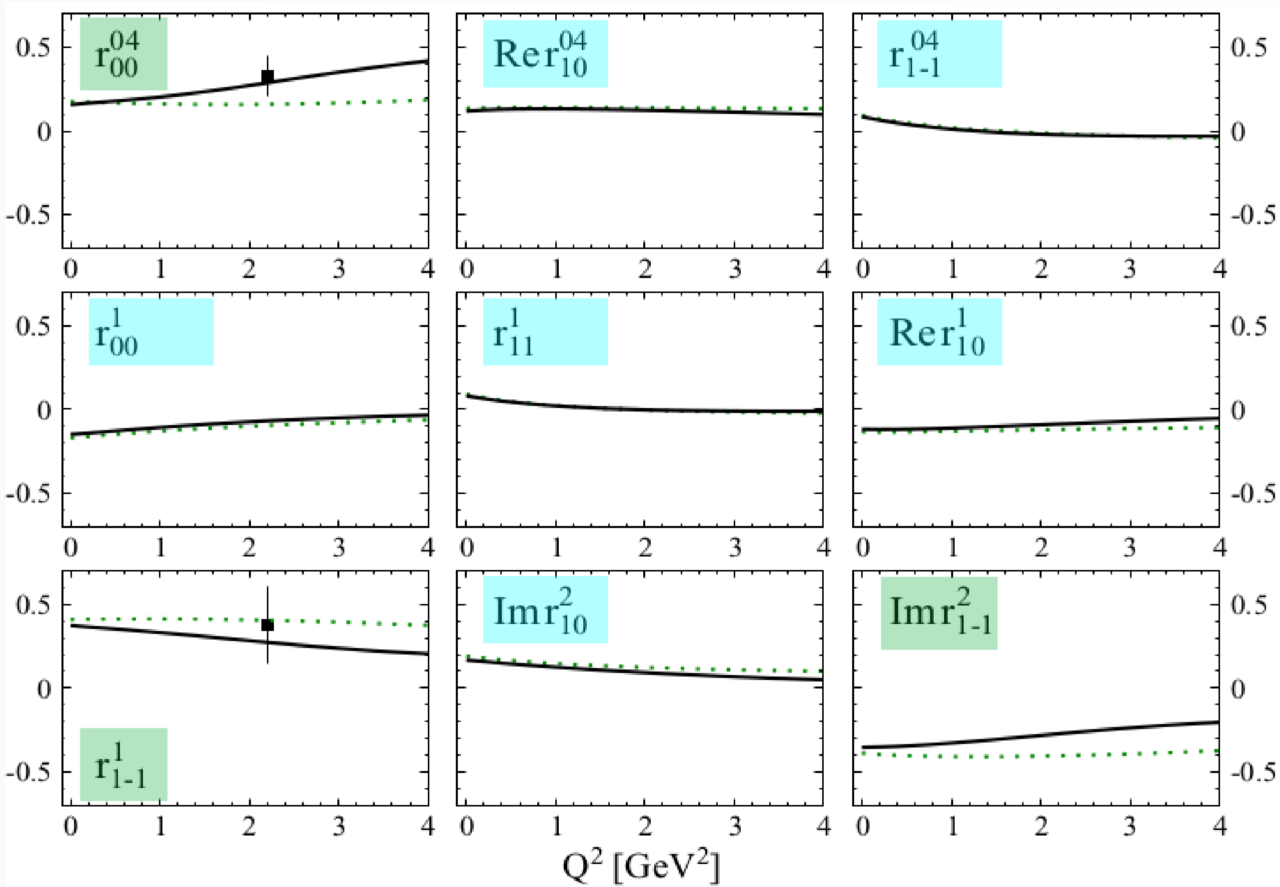


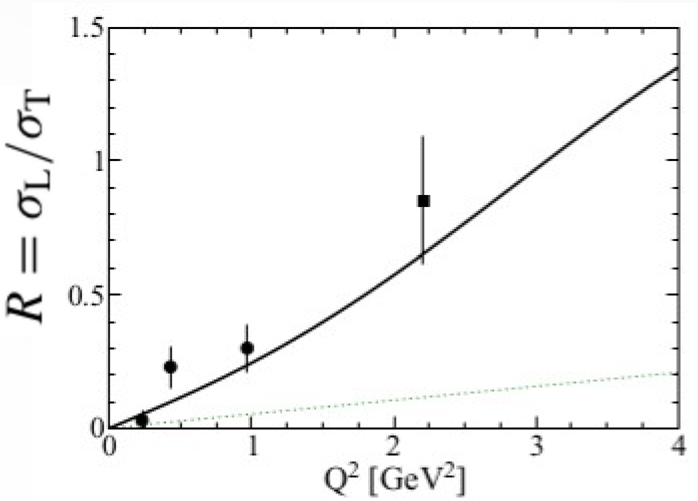
[Exp: CLAS, Santoro, PRC.78.025210 (2008)]

□ The signs of Pomeron and **meson** contributions are opposite to each other.
□ σ_{TT} and σ_{LT} become zero as W and Q^2 increases, indicating SCHC.

spin-density matrix elements (r_{ij}^k) at W = 2.5 GeV

a-5 $\gamma^* p \rightarrow \varphi p$





$$r_{ij}^{04} = \frac{\rho_{ij}^0 + \varepsilon R \rho_{ij}^4}{1 + \varepsilon R},$$

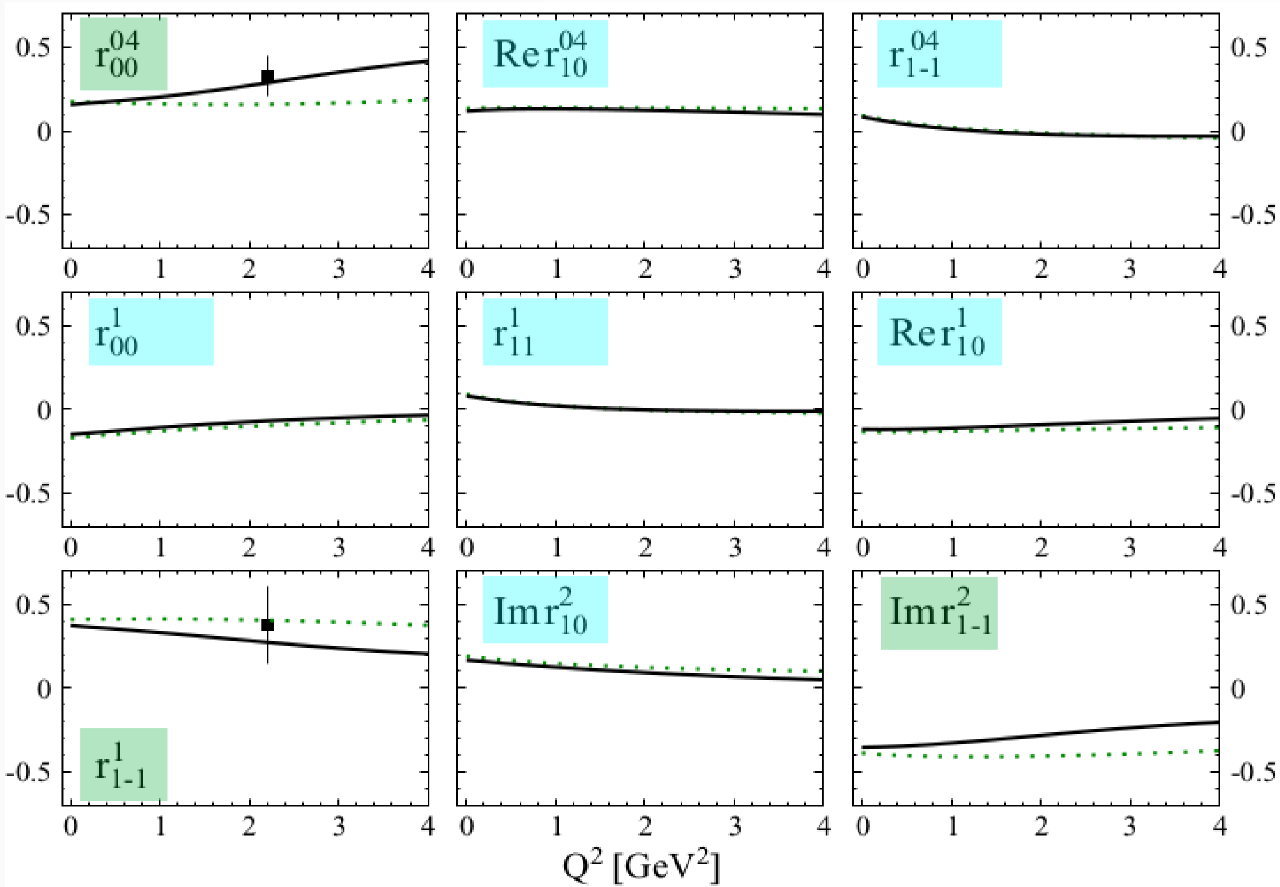
$$r_{ij}^{\alpha} = \frac{\rho_{ij}^{\alpha}}{1 + \varepsilon R}, \quad \text{for } \alpha = (0-3),$$

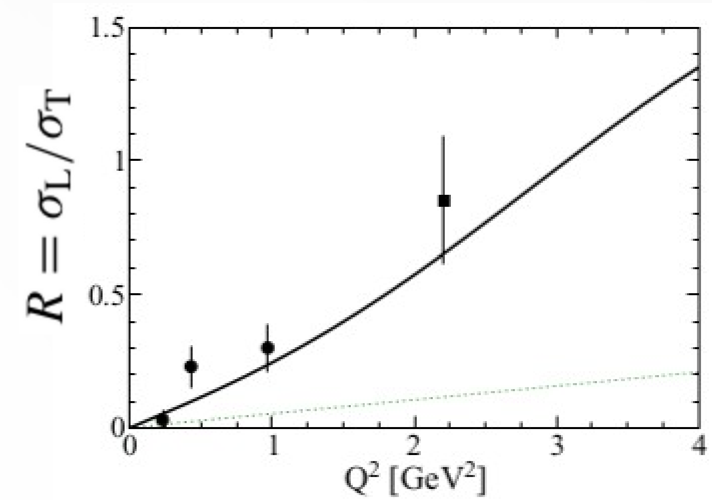
$$r_{ij}^{\alpha} = \sqrt{R}\frac{\rho_{ij}^{\alpha}}{1 + \varepsilon R}, \quad \text{for } \alpha = (5-8)$$

□ By definition, if SCHC holds, $r_{ij}^k = 0$, $r_{ij}^k \neq 0$.

spin-density matrix elements (r_{ij}^{k}) at W = 2.5 GeV

a-5 $\gamma^{*}\, p \rightarrow \varphi\, p$





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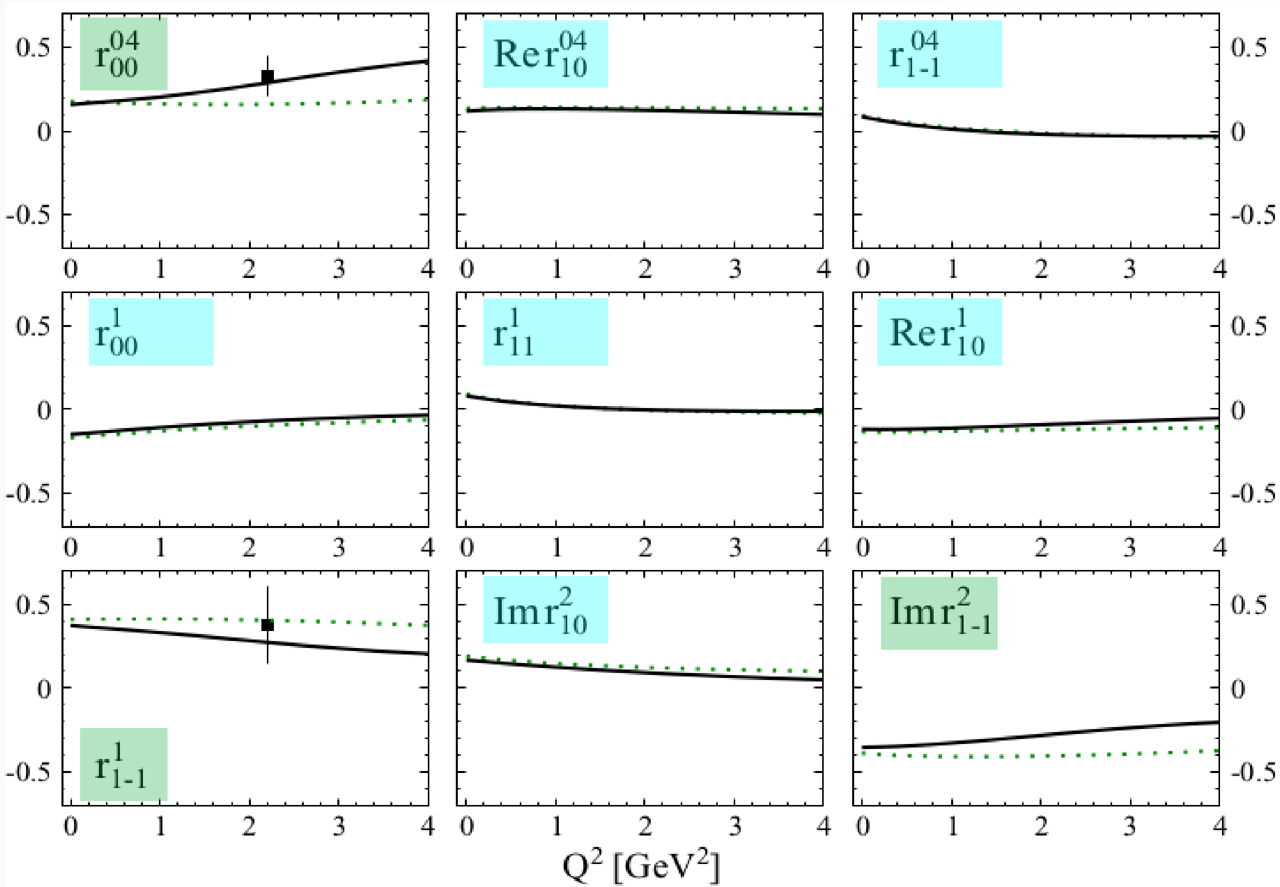
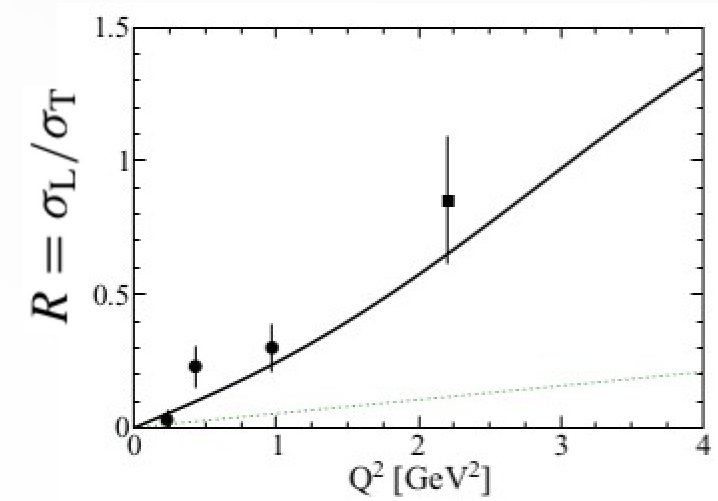
- By definition, if SCHC holds, $r_{ij}^{k} = 0$, $r_{ij}^{k} \neq 0$.
- $P \equiv \dfrac{\sigma_T^N - \sigma_T^U}{\sigma_T^N + \sigma_T^U} = (1 + \varepsilon R)(2r_{1-1}^{1} - r_{00}^{1})$: Parity asymmery Our result $\simeq 0.9$
- $1 - r_{00}^{04} + 2r_{1-1}^{04} - 2r_{11}^{1} - 2r_{1-1}^{1} = 0$ only if Natural parity exchange (σ^N). Our result $\simeq 0.1$

Exclusive electroproduction of vector mesons

spin-density matrix elements (r_{ij}^{k}) at W = 2.5 GeV

a-5 $\gamma^* p \to \varphi p$





$$r_{ij}^{04} = \frac{\rho_{ij}^{0} + \varepsilon R \rho_{ij}^{4}}{1 + \varepsilon R},$$

$$r_{ij}^{\alpha} = \frac{\rho_{ij}^{\alpha}}{1 + \varepsilon R}, \quad \text{for } \alpha = (0-3),$$

$$r_{ij}^{\alpha} = \sqrt{R}\frac{\rho_{ij}^{\alpha}}{1 + \varepsilon R}, \quad \text{for } \alpha = (5-8)$$

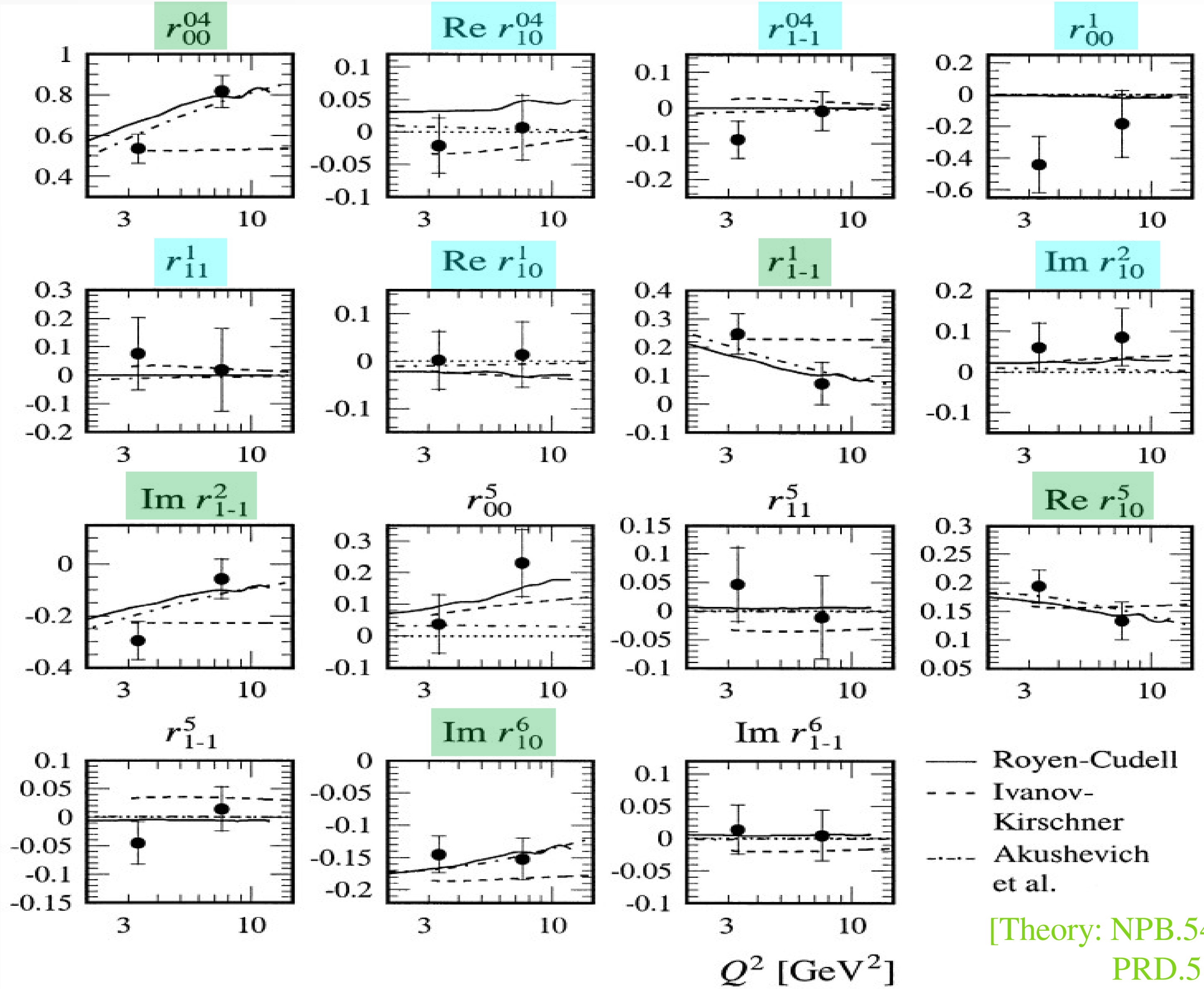
□ By definition, if SCHC holds, $r_{ij}^{k} = 0$, $r_{ij}^{k} \neq 0$.

□ The relative contributions of different meson exchanges are verified. □ SCHC seems to hold.

□ Our hadronic approach is very successful for describing the data at $Q^2 = (0\text{-}4)$ GeV², W = (2-5) GeV, t = (0-2) GeV².

spin-density matrix elements (r_{ij}^{k}) at W ~ 100 GeV

a-6 $\gamma^{*}\, p \to \varphi\, p$



$$r_{ij}^{04} = \frac{\rho_{ij}^{0} + \varepsilon R \rho_{ij}^{4}}{1+\varepsilon R},$$

$$r_{ij}^{\alpha} = \frac{\rho_{ij}^{\alpha}}{1+\varepsilon R}, \quad \text{for } \alpha = (0-3),$$

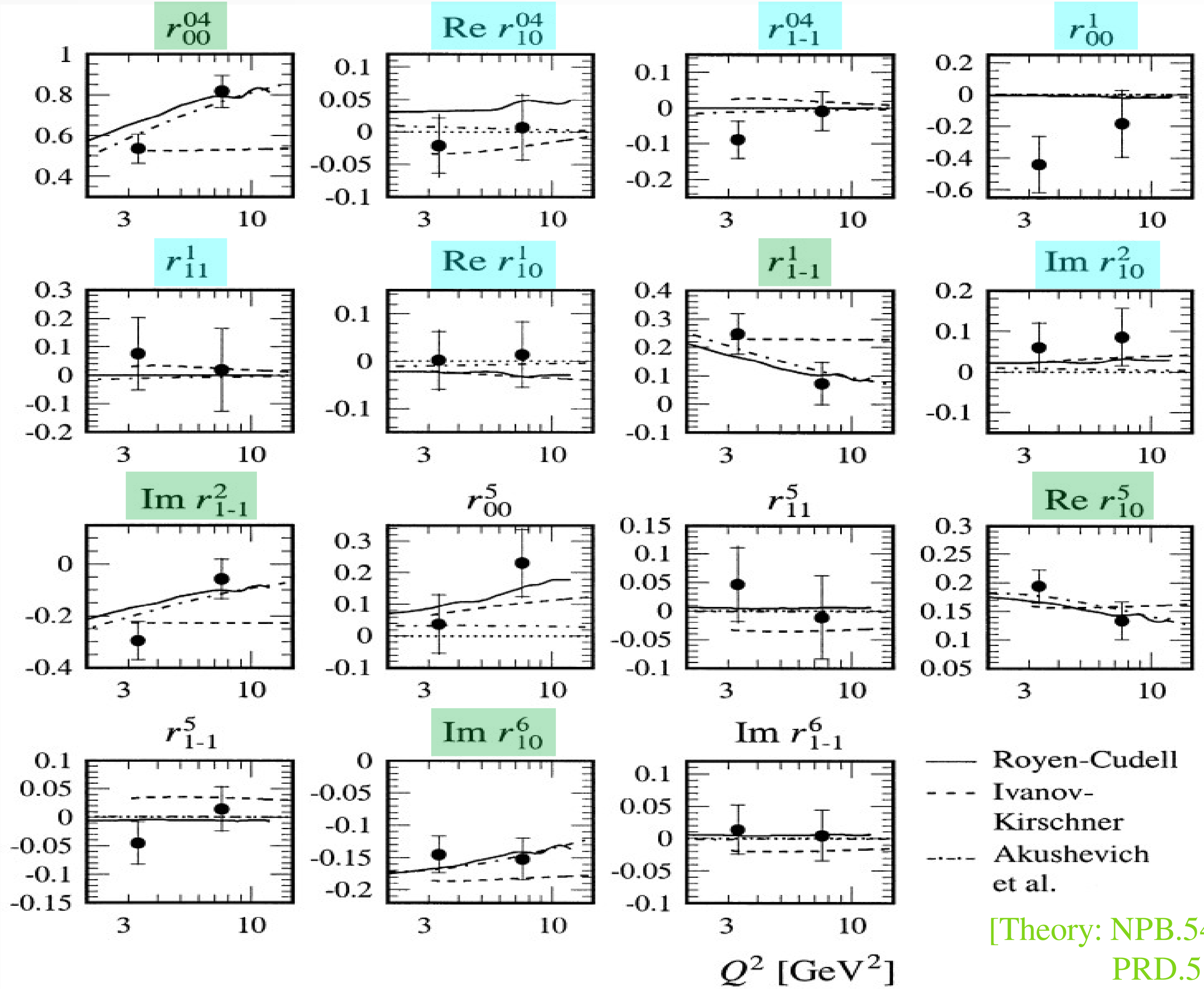
$$r_{ij}^{\alpha} = \sqrt{R}\frac{\rho_{ij}^{\alpha}}{1+\varepsilon R}, \quad \text{for } \alpha = (5-8)$$

[Theory: NPB.545.505 (1999)
PRD.58.114026 (1998)
JETP.L.69.294 (1999)]

[Exp: H1, Adloff, PLB.483.360 (2000)]

spin-density matrix elements (r_{ij}^{k}) at W ~ 100 GeV

a-6 $\gamma^{*}\, p \rightarrow \varphi\, p$



[Exp: H1, Adloff, PLB.483.360 (2000)]

[Theory: NPB.545.505 (1999)
PRD.58.114026 (1998)
JETP.L.69.294 (1999)]

- By definition, if SCHC holds, $r_{ij}^{k} = 0$, $r_{ij}^{k} \neq 0$.
- A small but significant violation of SCHC is found from the H1 data.
- A Pomeron, represented by the hard two-gluon exchange, can reproduce the main features of the HERA data for hard diffraction.
- We need more complete reaction theories to describe the HERA data.

Exclusive electroproduction of vector mesons

◇ Hard exclusive diffractive processes are the source of valuable information on the origin of small x processes, i.e., on the origin of the phenomenon known as Pomeron.

Exclusive electroproduction of vector mesons

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◇ Collaboration with T.-S.H.Lee (Argonne Natl. Lab.) and S.Sakinah (Kyungpook Natl. Univ.)
We have various theoretical tools to deal with the Pomeron exchange mechanism.
[T.-S.H.Lee, S.Sakinah, Yongseok Oh, EPJA.58.252(2022)]

□ Non-perturbative approach

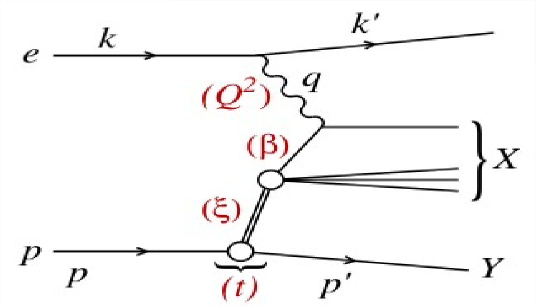
- Donnachie and Landshoff (Pom-DL) [NPB.244.322 (1983)]
- Its extension to include V-N potential extracted from LQCD (Pom-pot) [T.-S.H.Lee, arXiv:2004.13934]
- Constituent quark model (CQM) to account for the quark substructure of V (Pom-CQM) [T.-S.H.Lee]

□ Perturbative QCD approach

- Two-gluon exchange using the GPD of the nucleon (GPD-based) [T.-S.H.Lee]
- Two- & three-gluon exchanges using the parton distribution of the nucleon (2g+3g) [Brodsky, PLB.498.23 (2001)]
- Exchanges of scalar & tensor glueballs within the holographic formulation (holog) [Mamo, PRD.104.066023 (2021)]

Inclusive diffraction

- Inclusive diffraction has been extensively studied at HERA.
- There are number of areas where the EIC can significantly expand our knowledge of QCD diffraction.



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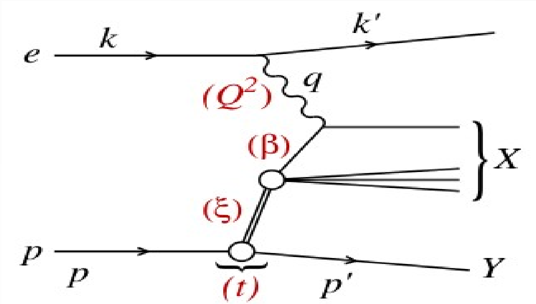
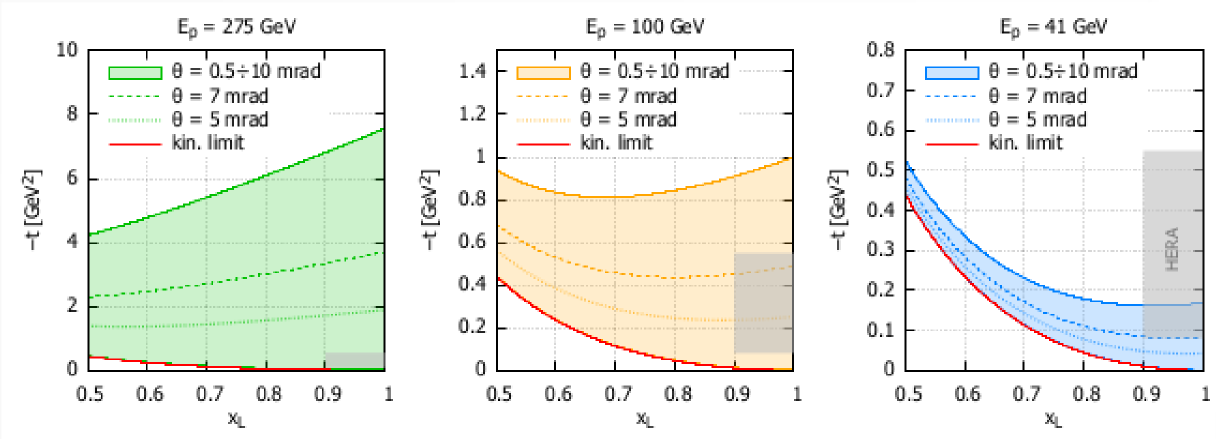


First, thanks to the instrumentation in forward Region, EIC will be able to measure leading protons in a much wider range of t and x_L than at HERA.



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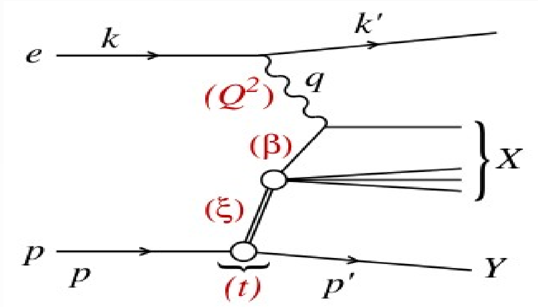

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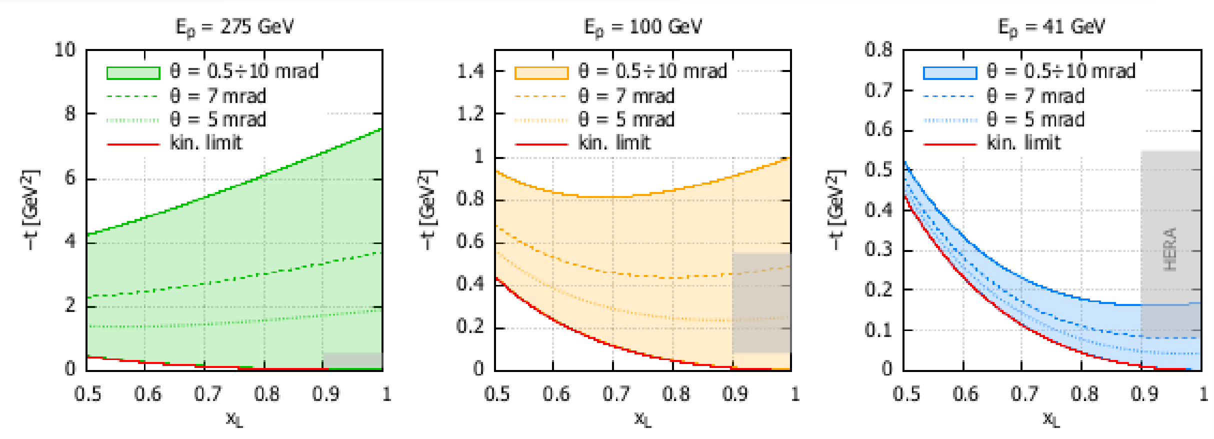
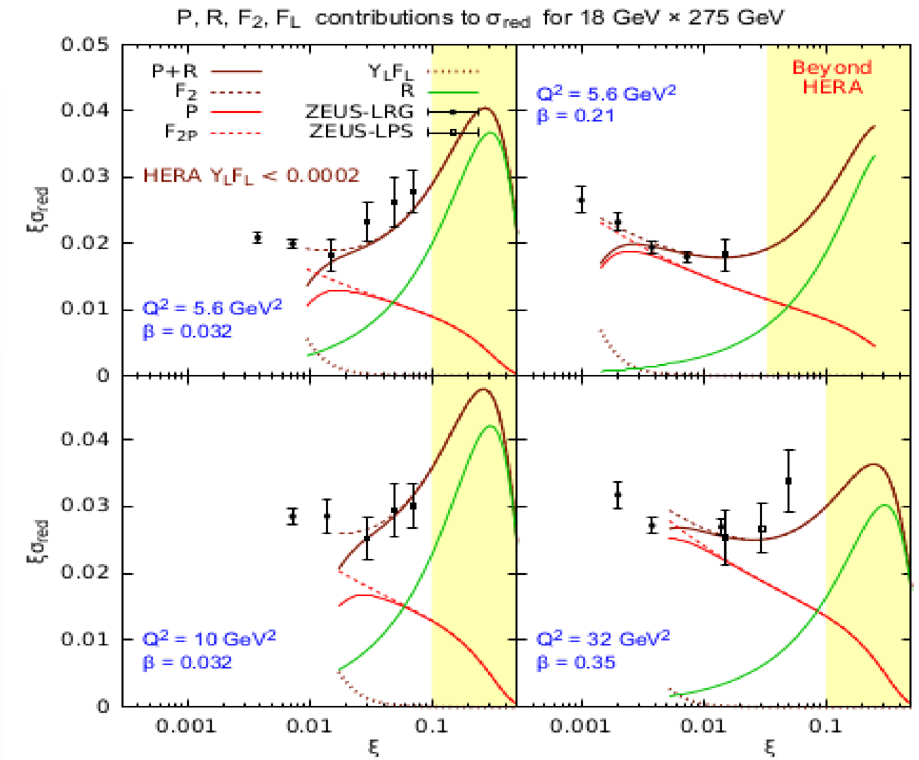
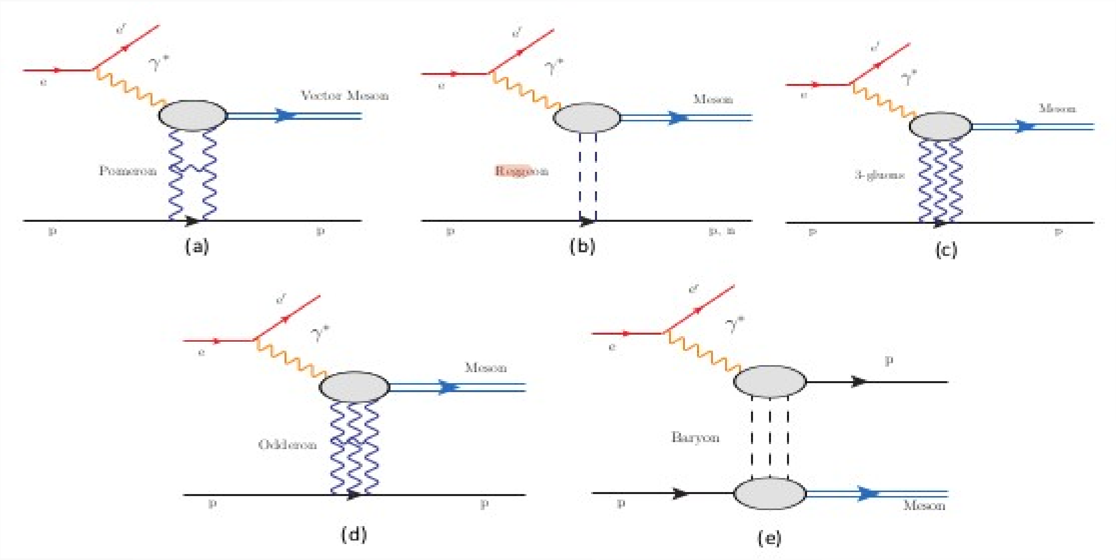


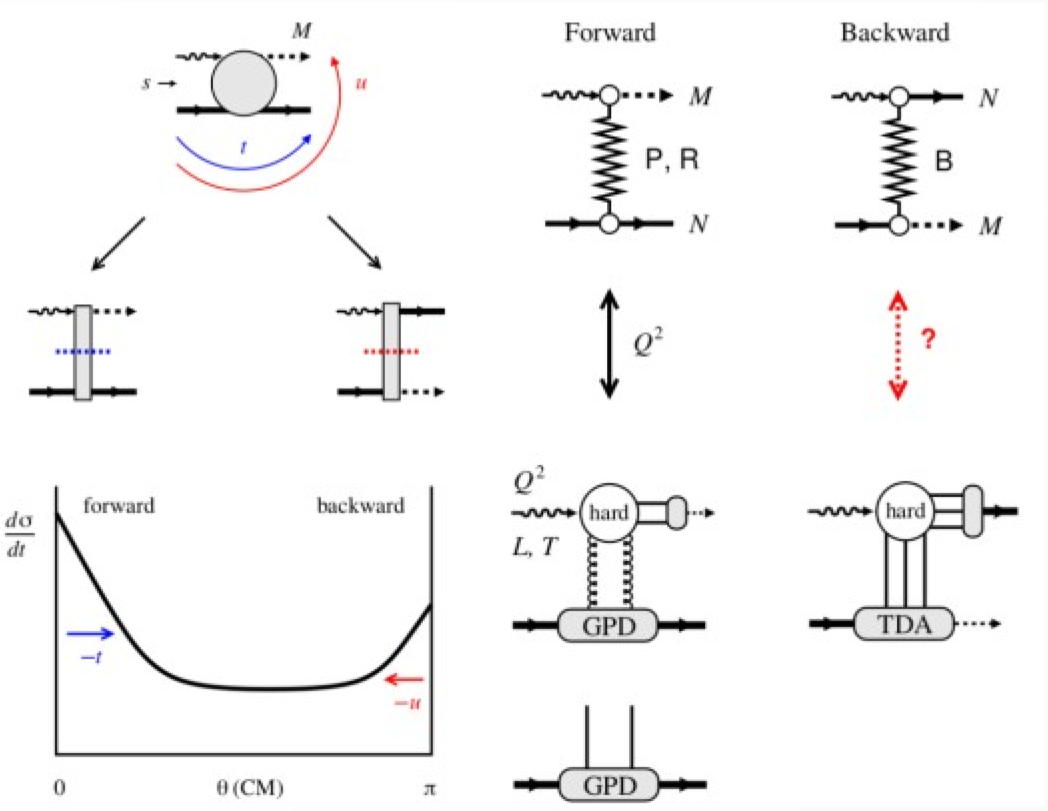
EIC has the potential to explore the region ($\zeta > 0.1$) to disentangle the two components.
EIC will provide excellent opportunities to perform precise measurements of the longitudinal diffractive SF.



The **second** area where EIC could provide valuable information are the Pomeron & Reggeon contributions. At HERA, the t-dep. of the Reggeon contribution could not be tested at all.

□ Odderon exchange, u-Channel exclusive meson electroproduction ...

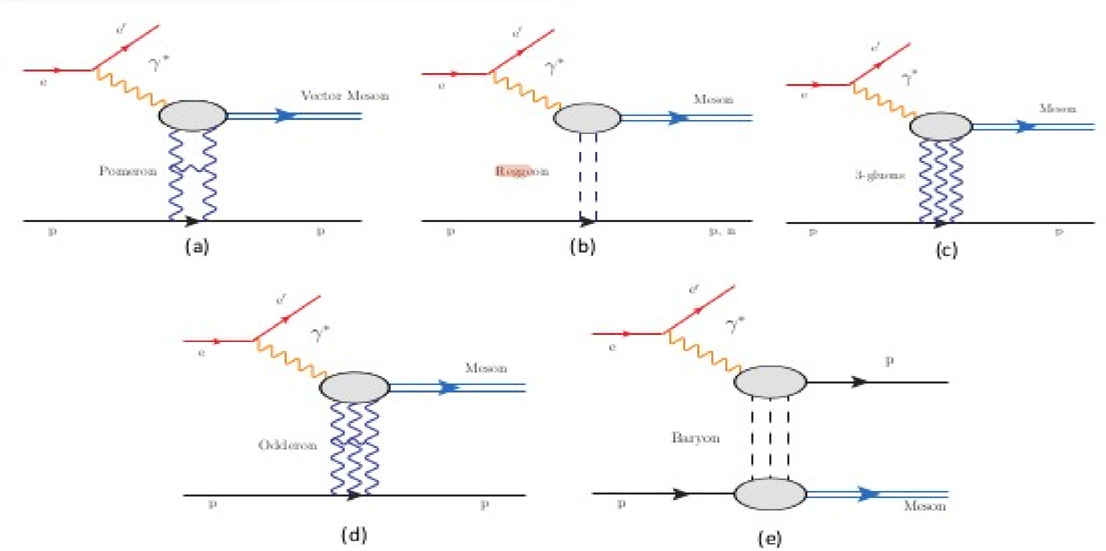


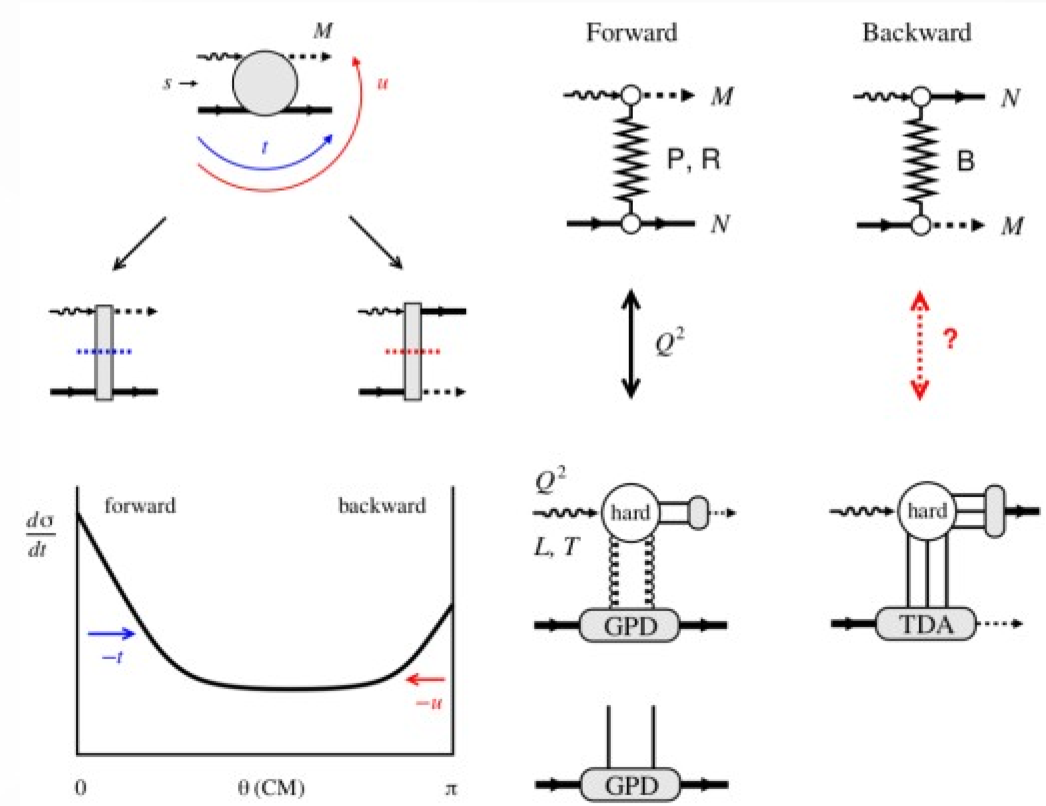


(left) Soft-hard-soft structure transition
(right) Forward-backward factorization scheme

[EIC Yellow Report] 7.4.5. New particle production mechanisms

□ Odderon exchange, *u*-Channel exclusive meson electroproduction ...





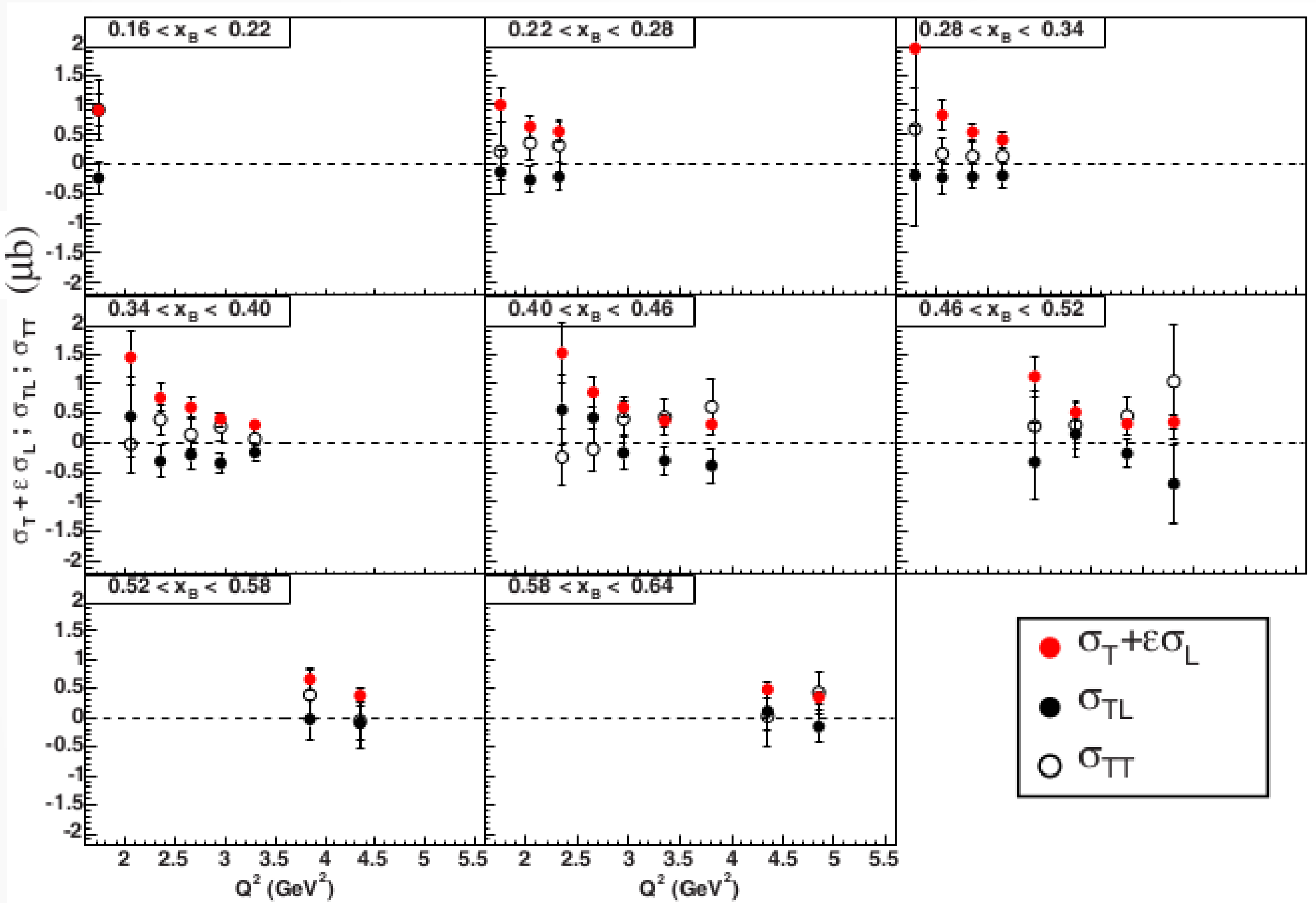
(left) Soft-hard-soft structure transition
(right) Forward-backward factorization scheme

Combining the data collected at JLab 12 GeV and EIC, we aim to accomplish the following objectives to unveil the complete physics meaning of u-channel interactions:

- At low Q^2 limit: $Q^2 < 2\ \text{GeV}^2$, mapping out the W dependence for electroproduction of all mesons at near-backward kinematics.
- Extracting the u-dependence ($\sigma \propto e^{-b \cdot u}$) as a function of Q^2. This could be used to study the transition from a "soft" Regge-exchange type picture (transverse size of interaction is of order of the hadronic size) to the "hard" QCD regime.
- Studying the model effectiveness between the hadronic Regge based (exchanges of mesons and baryons) and the partonic description through Transition Distribution Amplitudes (exchanges of quarks and gluons), is equivalent to studying the non-perturbative to perturbative QCD transition.

T-L separated cross sections at low W

b-1 $\gamma^* \, p \to \rho(770)\, p$



[Exp: CLAS, Morrow, EPJA.39.5 (2009)]

$$\frac{1}{\mathcal{N}}\frac{d\sigma_{\rm T}}{dt} = \frac{1}{2}\sum_{\lambda_\gamma=\pm1}\overline{|\mathcal{M}^{(\lambda_\gamma)}|^2},$$

$$\frac{1}{\mathcal{N}}\frac{d\sigma_{\rm L}}{dt} = \overline{|\mathcal{M}^{(\lambda_\gamma=0)}|^2},$$

$$\frac{1}{\mathcal{N}}\frac{d\sigma_{\rm TT}}{dt} = -\frac{1}{2}\sum_{\lambda_\gamma=\pm1}\overline{\mathcal{M}^{(\lambda_\gamma)}\mathcal{M}^{(-\lambda_\gamma)*}},$$

$$\frac{1}{\mathcal{N}}\frac{d\sigma_{\rm LT}}{dt} = -\frac{1}{2\sqrt{2}}\sum_{\lambda_\gamma=\pm1}\lambda_\gamma\,(\overline{\mathcal{M}^{(0)}\mathcal{M}^{(\lambda_\gamma)*}} + \overline{\mathcal{M}^{(\lambda_\gamma)}\mathcal{M}^{(0)*}})$$

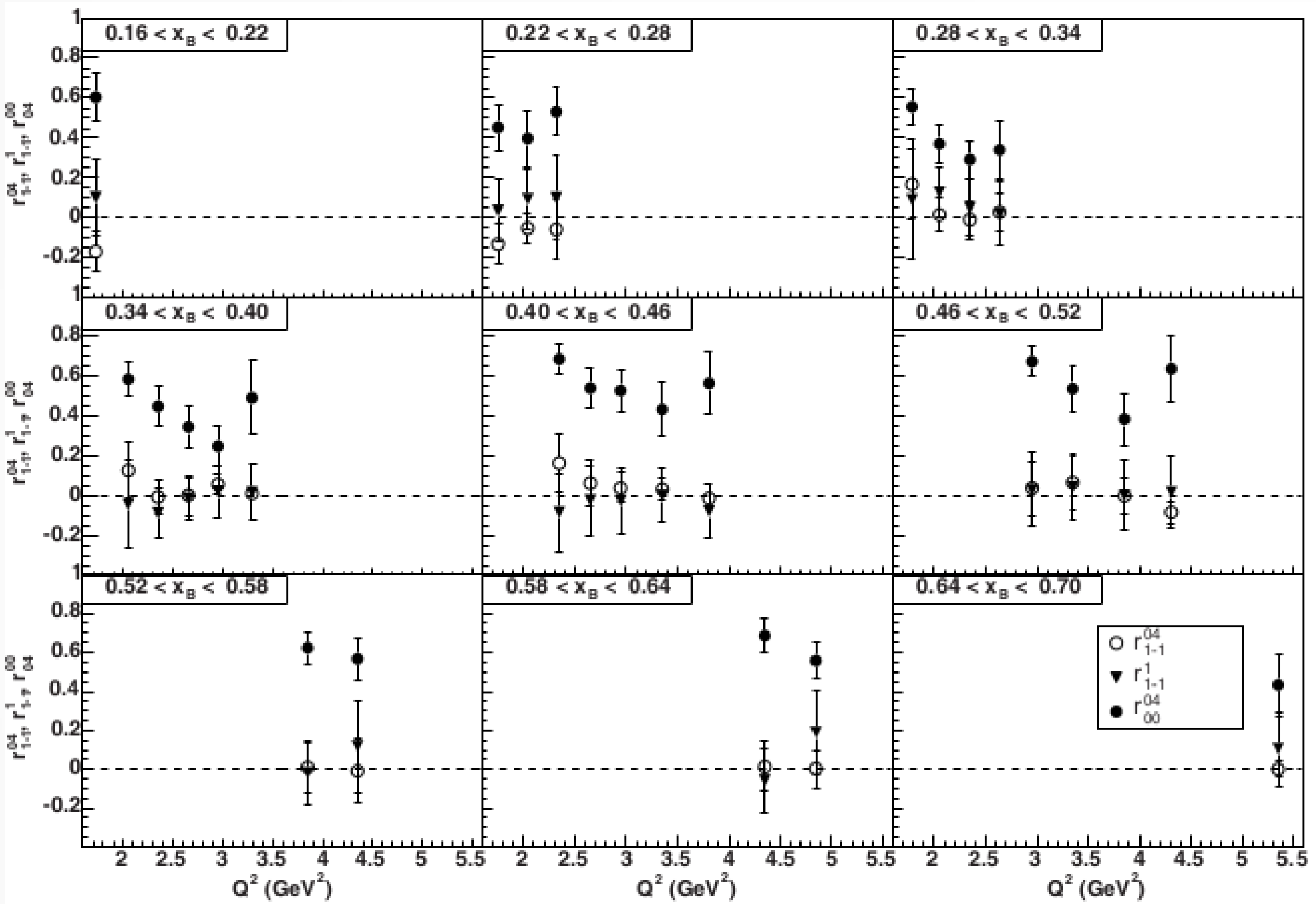
□ If SCHC holds, σ_{TT} and σ_{LT} become zero.

- Pomeron > meson-exchange ($\gamma^* \, p \to \varphi\, p$)
  Pomeron < meson-exchange ($\gamma^* \, p \to \rho\, p,\ \omega\, p$)

Exclusive electroproduction of vector mesons

spin-density matrix elements (r_{ij}^{k}) at low W

b-2 $\gamma^* p \to \rho(770)\, p$



= 0 if SCHC holds

$$r_{ij}^{04} = \frac{\rho_{ij}^{0} + \varepsilon R \rho_{ij}^{4}}{1 + \varepsilon R},$$

$$r_{ij}^{\alpha} = \frac{\rho_{ij}^{\alpha}}{1 + \varepsilon R}, \quad \text{for} \quad \alpha = (0-3),$$

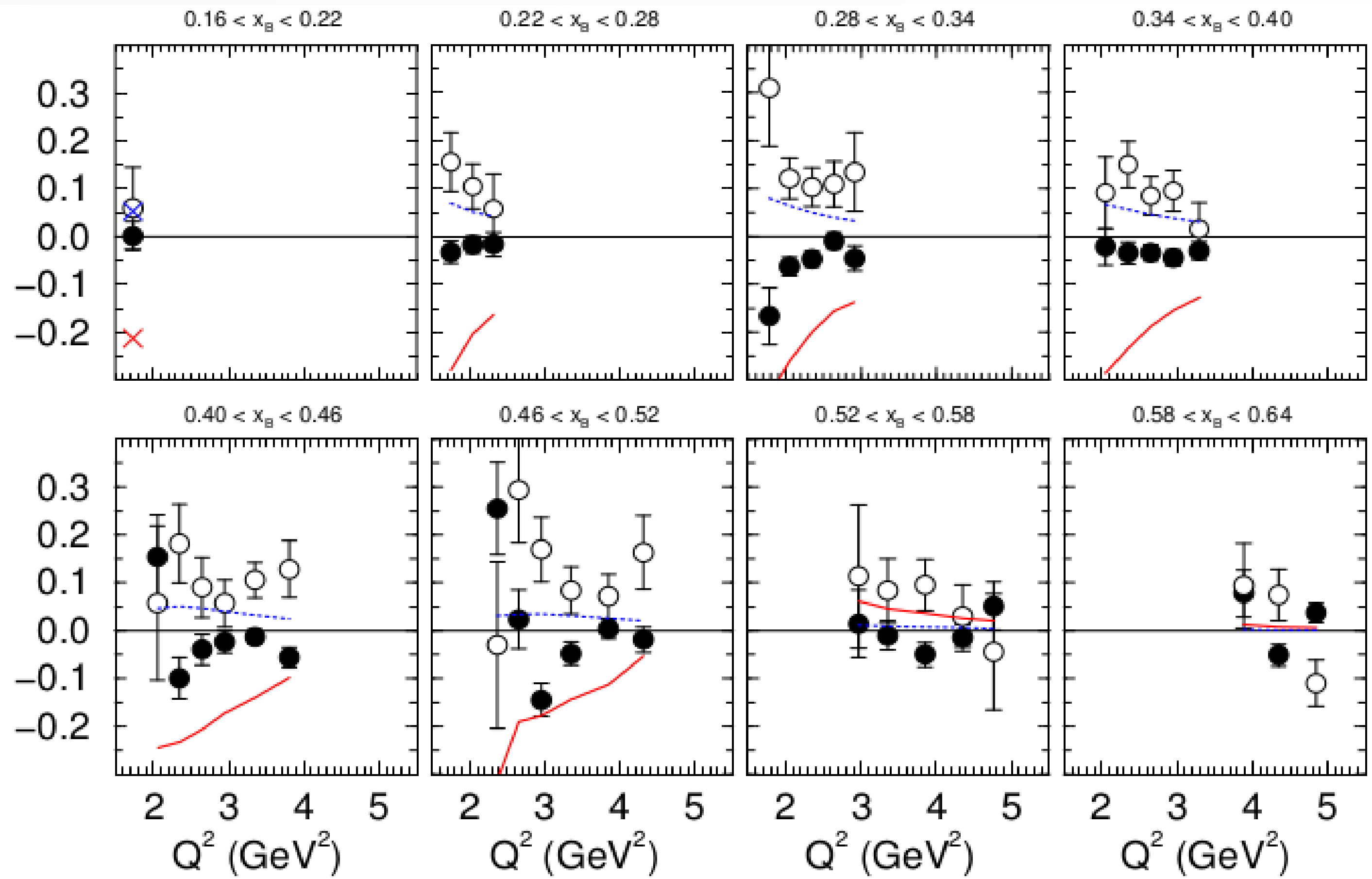
$$r_{ij}^{\alpha} = \sqrt{R}\frac{\rho_{ij}^{\alpha}}{1 + \varepsilon R}, \quad \text{for} \quad \alpha = (5-8)$$

[Exp: CLAS, Morrow, EPJA.39.5 (2009)]

□ It is difficult to draw a firm conclusion concerning SCHC although most physical observables seem to support SCHC.

T-L separated cross sections at low W

c-1 $\gamma^* p \rightarrow \omega(782)\, p$



● σ_{TL}
○ σ_{TT}

[Exp: CLAS, Morrow, EPJA.39.5 (2009)]

$$\frac{1}{\mathcal{N}}\frac{d\sigma_T}{dt} = \frac{1}{2}\sum_{\lambda_\gamma=\pm1}\overline{|\mathcal{M}^{(\lambda_\gamma)}|^2},$$

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$$\frac{1}{\mathcal{N}}\frac{d\sigma_{TT}}{dt} = -\frac{1}{2}\sum_{\lambda_\gamma=\pm1}\overline{\mathcal{M}^{(\lambda_\gamma)}\mathcal{M}^{(-\lambda_\gamma)*}},$$

$$\frac{1}{\mathcal{N}}\frac{d\sigma_{LT}}{dt} = -\frac{1}{2\sqrt{2}}\sum_{\lambda_\gamma=\pm1}\lambda_\gamma\left(\overline{\mathcal{M}^{(0)}\mathcal{M}^{(\lambda_\gamma)*}} + \overline{\mathcal{M}^{(\lambda_\gamma)}\mathcal{M}^{(0)*}}\right)$$

Regge-based model

[Laget, PRD.70.054023 (2004)]

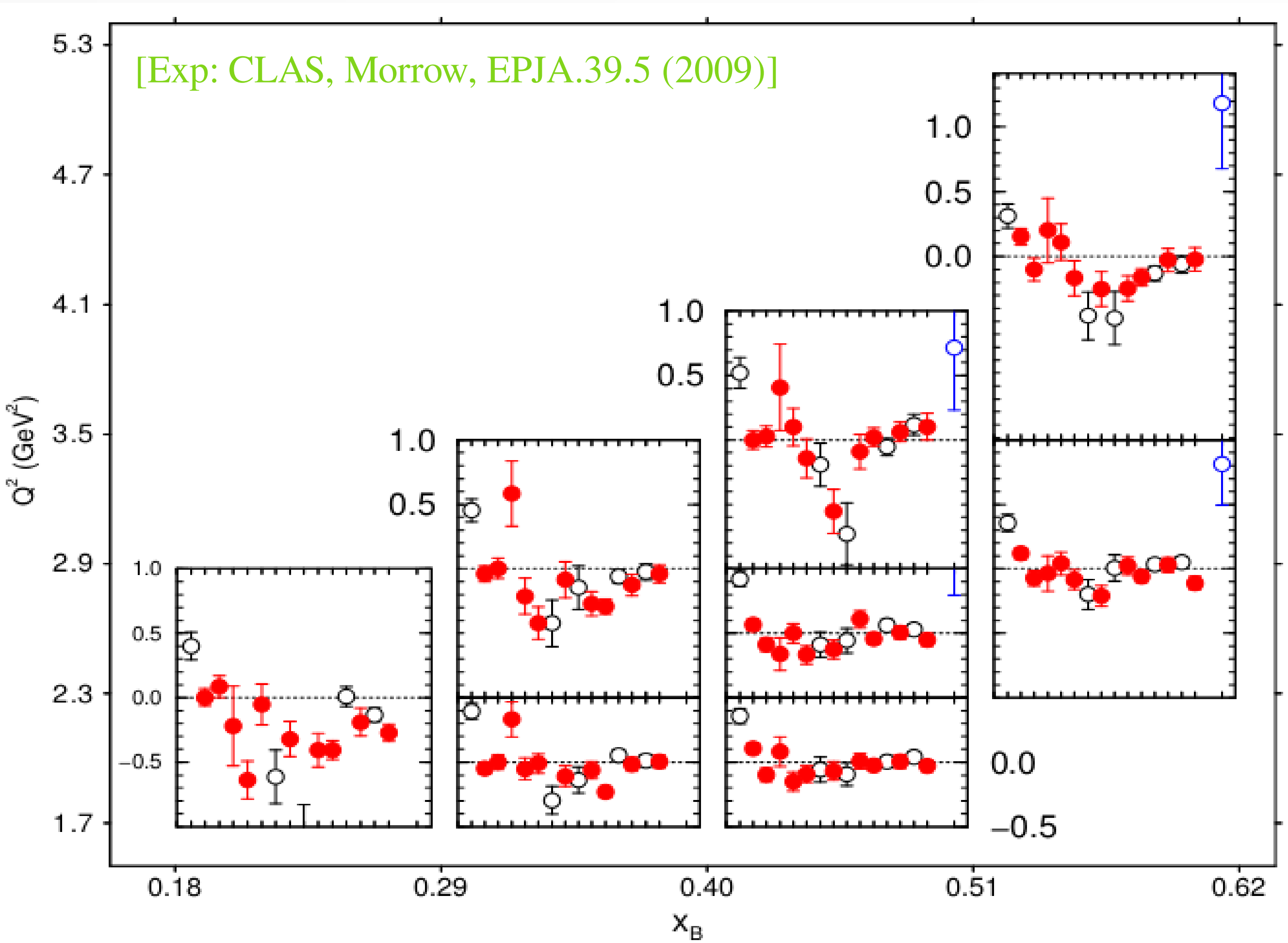
- If SCHC holds, σ_{TT} and σ_{LT} become zero.
  - Pomeron > meson-exchange ($\gamma^* p \rightarrow \varphi\, p$)

    Pomeron < meson-exchange ($\gamma^* p \rightarrow \rho\, p$, $\omega\, p$)

Exclusive electroproduction of vector mesons

spin-density matrix elements (r_{ij}^k) at low W

c-2 $\gamma^* p \to \omega(782)\, p$



$$r_{ij}^{04} = \frac{\rho_{ij}^0 + \varepsilon R \rho_{ij}^4}{1+\varepsilon R},$$

$$r_{ij}^{\alpha} = \frac{\rho_{ij}^{\alpha}}{1+\varepsilon R}, \quad \text{for } \alpha = (0-3),$$

$$r_{ij}^{\alpha} = \sqrt{R}\frac{\rho_{ij}^{\alpha}}{1+\varepsilon R}, \quad \text{for } \alpha = (5-8)$$

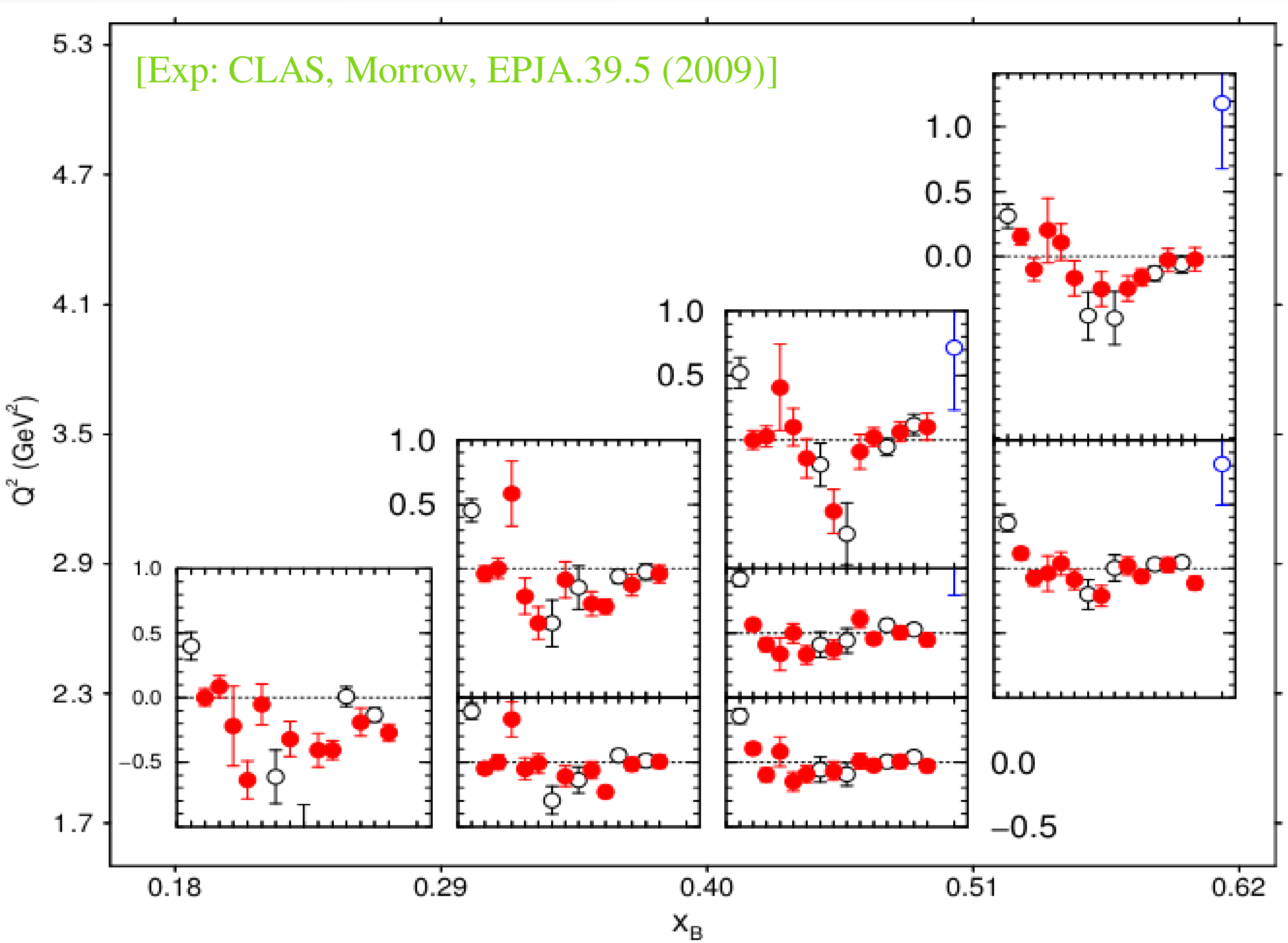
□ r^{04}_{00}, $\mathrm{Re}\,r^{04}_{10}$, r^{04}_{1-1}, r^{1}_{00}, r^{1}_{11}, $\mathrm{Re}\,r^{1}_{10}$, r^{1}_{1-1}, $\mathrm{Im}\,r^{2}_{10}$, $\mathrm{Im}\,r^{2}_{1-1}$, r^{5}_{00}, r^{5}_{11}, $\mathrm{Re}\,r^{5}_{10}$, r^{5}_{1-1}, $\mathrm{Im}\,r^{6}_{10}$, $\mathrm{Im}\,r^{6}_{1-1}$

□ SCHC holds, if $r_{ij}^k = 0$. It seems that SCHC is broken.

Exclusive electroproduction of vector mesons

spin-density matrix elements (r_{ij}^{k}) at low W

c-2 $\gamma^* p \to \omega(782)\, p$



$$r_{ij}^{04} = \frac{\rho_{ij}^{0} + \varepsilon R \rho_{ij}^{4}}{1+\varepsilon R},$$

$$r_{ij}^{\alpha} = \frac{\rho_{ij}^{\alpha}}{1+\varepsilon R}, \quad \text{for } \alpha = (0-3),$$

$$r_{ij}^{\alpha} = \sqrt{R}\frac{\rho_{ij}^{\alpha}}{1+\varepsilon R}, \quad \text{for } \alpha = (5-8)$$

□ Theoretical studies on $\gamma^* p \to (\rho, \omega)\, p$ at low Q^2 and W are very rare. We need further investigation.

□ r_{00}^{04}, $\mathrm{Re}\, r_{10}^{04}$, r_{1-1}^{04}, r_{00}^{1}, r_{11}^{1}, $\mathrm{Re}\, r_{10}^{1}$, r_{1-1}^{1}, $\mathrm{Im}\, r_{10}^{2}$, $\mathrm{Im}\, r_{1-1}^{2}$, r_{00}^{5}, r_{11}^{5}, $\mathrm{Re}\, r_{10}^{5}$, r_{1-1}^{5}, $\mathrm{Im}\, r_{10}^{6}$, $\mathrm{Im}\, r_{1-1}^{6}$

□ SCHC holds, if $r_{ij}^{k} = 0$. It seems that SCHC is broken.

◇ For $\gamma\, p \to \varphi\, p$ & $\gamma^*\, p \to \varphi\, p$, we studied the relative contributions between the Pomeron and various meson exchanges.
The light-meson (π, η, a_0, f_0,...) contribution is crucial to describe the data at low W & Q^2.

◇ For $\gamma^*\, p \to V\, p$, from the data of separated cross sections (σ_{TT}, σ_{LT}) and SDMEs (r_{ij}^k), we can test whether helicity is conserved or not in three different frames.

$\gamma^*\, p \to \varphi\, p$: SCHC is conserved (low W & Q^2), is broken (high W & Q^2 at HERA).
$\gamma^*\, p \to \rho\, p$: SCHC seems to hold (low W & Q^2).
$\gamma^*\, p \to \omega\, p$: SCHC is broken (low W & Q^2).

◇ Extension to $\gamma^{(*)}\, A \to V[\varphi, J/\psi, \Upsilon(1S)]\, A$, [A = ^{2}H, ^{4}He, ^{12}C,…]
$\gamma\, {}^4\mathrm{He} \to \varphi\, {}^4\mathrm{He}$ [S.H.Kim, T.S.H.Lee, S.i.Nam, Y. Oh, PRC.104.045202 (2021)]
> A distorted-wave impulse approximation within the multiple scattering formulation

◇ We plan to employ various Pomeron models to the soft and hard diffractive processes.

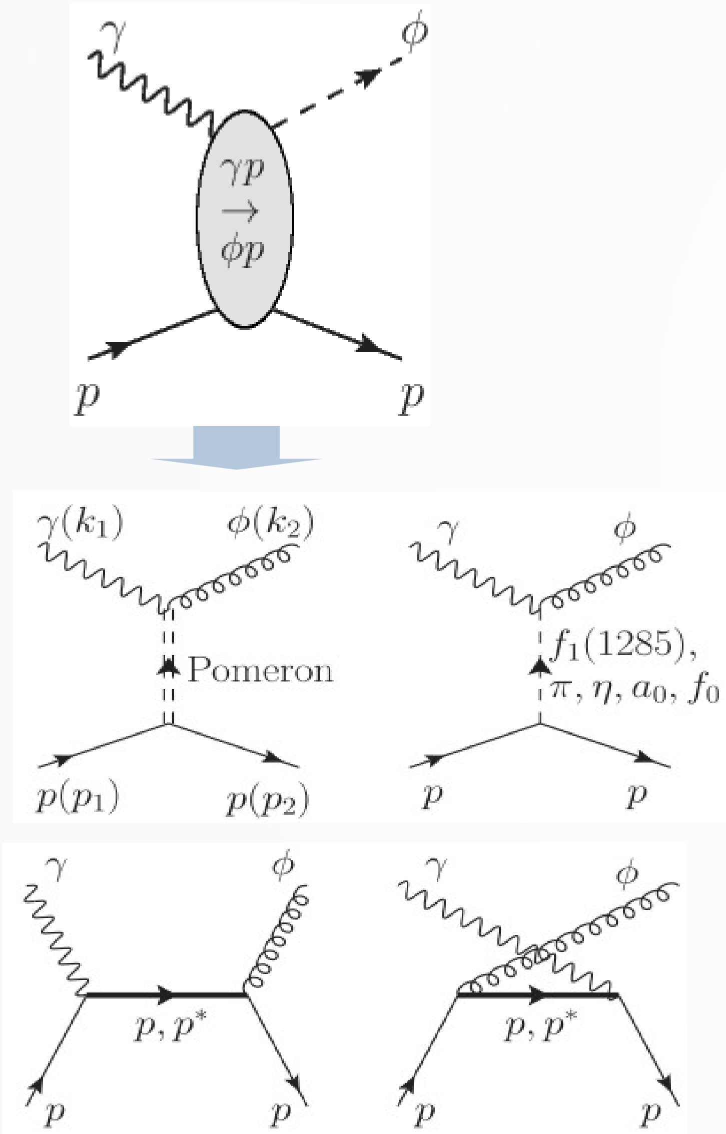
◇ Electron-Ion Collider (EIC) will carry out the relevant experiments in the future.

Thank you very much for your attention

Back Up

Born term

❑ Scattering amplitude: $T_{\phi N,\gamma N}(E) = [B_{\phi N,\gamma N} \quad]$



□ Ward-Takahashi identity

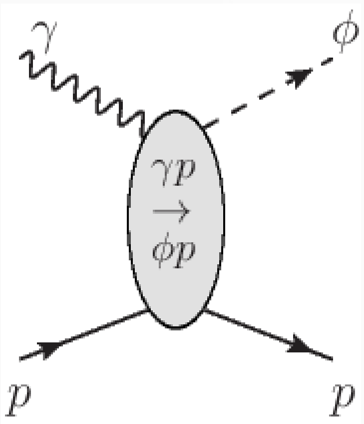
$$\mathcal{M}(k) = \epsilon_\mu(k)\mathcal{M}^\mu(k)$$

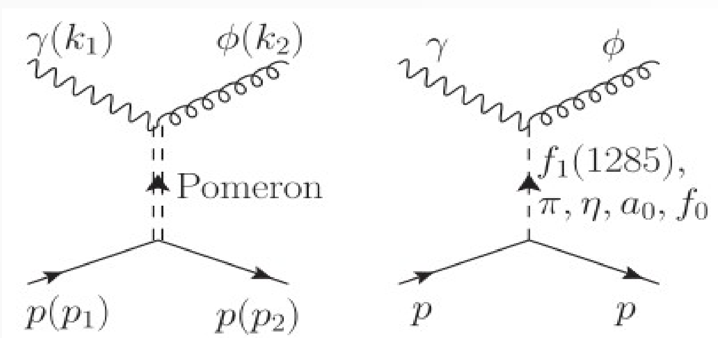
if we replace ϵ_μ with k_μ:

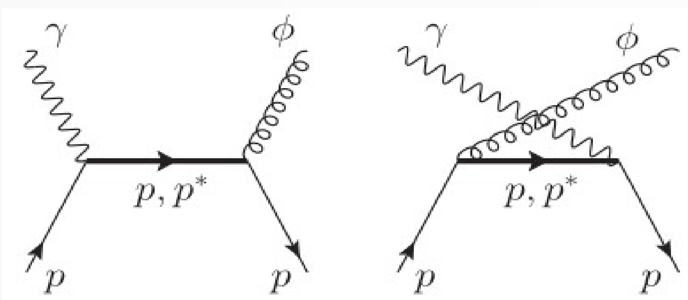
$$k_\mu \mathcal{M}^\mu(k) = 0$$

Born term

❑ Scattering amplitude: $T_{\phi N,\gamma N}(E) = [B_{\phi N,\gamma N} \quad]$







❑ Effective Lagrangians

□ EM vertex

$$\mathcal{L}_{\gamma\phi f_1} = g_{\gamma\phi f_1}\epsilon^{\mu\nu\alpha\beta}\partial_\mu A_\nu \partial^\lambda \partial_\lambda \phi_\alpha f_{1\beta}$$

$$\mathcal{L}_{\gamma\Phi\phi} = \frac{e g_{\gamma\Phi\phi}}{M_\phi}\epsilon^{\mu\nu\alpha\beta}\partial_\mu A_\nu \partial_\alpha \phi_\beta \Phi$$

$$\mathcal{L}_{\gamma S\phi} = \frac{e g_{\gamma S\phi}}{M_\phi} F^{\mu\nu}\phi_{\mu\nu} S$$

□ strong vertex

$$\mathcal{L}_{f_1 NN} = -g_{f_1 NN}\bar{N}\left[\gamma_\mu - i\frac{\kappa_{f_1 NN}}{2M_N}\gamma_\nu\gamma_\mu\partial^\nu\right] f_1^\mu \gamma_5 N$$

$$\mathcal{L}_{\Phi NN} = -\, i g_{\Phi NN}\bar{N}\Phi\gamma_5 N$$

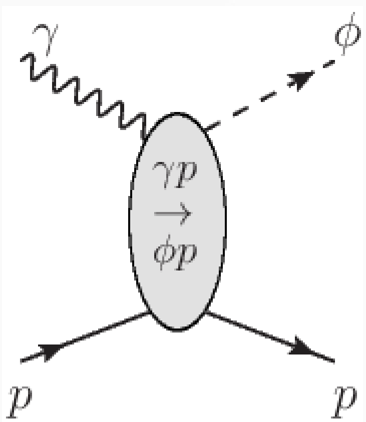
$$\mathcal{L}_{SNN} = -\, g_{SNN}\bar{N} S N$$

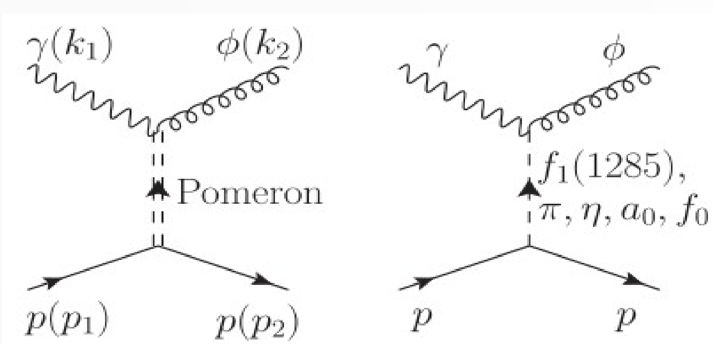
$$\mathcal{L}_{\gamma NN} = -\, e\bar{N}\left[\gamma_\mu - \frac{\kappa_N}{2M_N}\sigma_{\mu\nu}\partial^\nu\right] N A^\mu$$

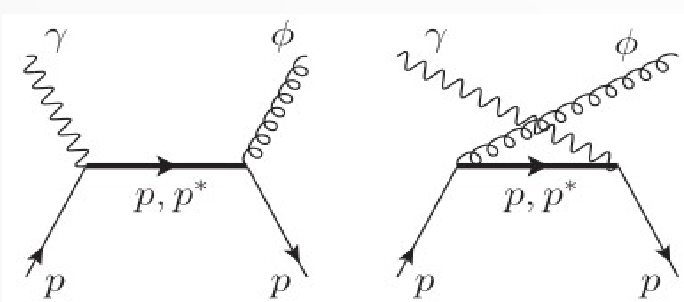
$$\mathcal{L}_{\phi NN} = -\, g_{\phi NN}\bar{N}\left[\gamma_\mu - \frac{\kappa_{\phi NN}}{2M_N}\sigma_{\mu\nu}\partial^\nu\right] N \phi^\mu$$

Born term

❑ Scattering amplitude: $T_{\phi N,\gamma N}(E) = [B_{\phi N,\gamma N} \quad]$







$$\mathcal{M} = \varepsilon^*_\nu \bar{u}_{N'} \mathcal{M}^{\mu\nu} u_N \epsilon_\mu$$

$$\mathcal{M}^{\mu\nu}_{f_1} = i\frac{M^2_\phi g_{\gamma f_1 \phi} g_{f_1 NN}}{t - M^2_{f_1}} \epsilon^{\mu\nu\alpha\beta}\left[-g_{\alpha\lambda} + \frac{q_{t\alpha} q_{t\lambda}}{M^2_{f_1}}\right] \times \left[\gamma^\lambda + \frac{\kappa_{f_1 NN}}{2M_N}\gamma^\sigma\gamma^\lambda q_{t\sigma}\right]\gamma_5 k_{1\beta},$$

$$\mathcal{M}^{\mu\nu}_{\Phi} = i\frac{e}{M_\phi}\frac{g_{\gamma\Phi\phi} g_{\Phi NN}}{t - M^2_\Phi}\epsilon^{\mu\nu\alpha\beta} k_{1\alpha} k_{2\beta}\gamma_5,$$

$$\mathcal{M}^{\mu\nu}_{S} = \frac{e}{M_\phi}\frac{2 g_{\gamma S\phi} g_{SNN}}{t - M^2_S + i\Gamma_S M_S}(k_1 k_2 g^{\mu\nu} - k^\mu_1 k^\nu_2),$$

$$\mathcal{M}^{\mu\nu}_{\phi\,\mathrm{rad},s} = \frac{e g_{\phi NN}}{s - M^2_N}\left(\gamma^\nu - i\frac{\kappa_{\phi NN}}{2M_N}\sigma^{\nu\alpha}k_{2\alpha}\right)(\not{q}_s + M_N) \times \left(\gamma^\mu + i\frac{\kappa_N}{2M_N}\sigma^{\mu\beta}k_{1\beta}\right),$$

$$\mathcal{M}^{\mu\nu}_{\phi\,\mathrm{rad},u} = \frac{e g_{\phi NN}}{u - M^2_N}\left(\gamma^\mu + i\frac{\kappa_N}{2M_N}\sigma^{\mu\alpha}k_{1\alpha}\right)(\not{q}_u + M_N) \times \left(\gamma^\nu - i\frac{\kappa_{\phi NN}}{2M_N}\sigma^{\nu\beta}k_{2\beta}\right),$$

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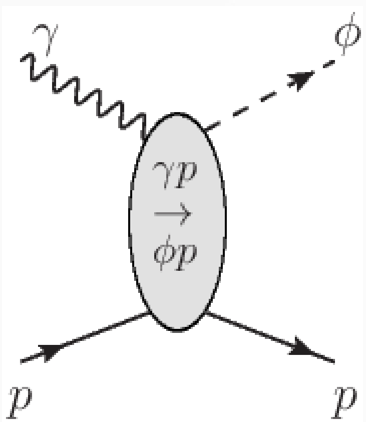
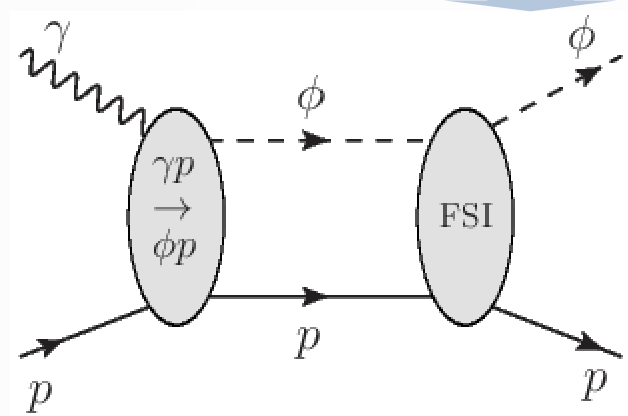
$$\mathcal{L}_{\phi NN} = -g_{\phi NN}\bar{N}\left[\gamma_\mu - \frac{\kappa_{\phi NN}}{2M_N}\sigma_{\mu\nu}\partial^\nu\right] N \phi^\mu$$

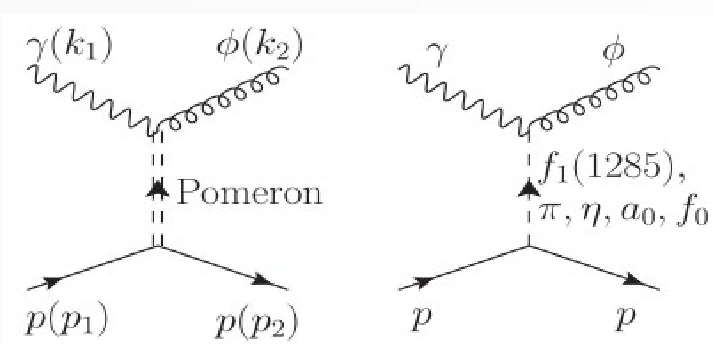
final state interaction (FSI)

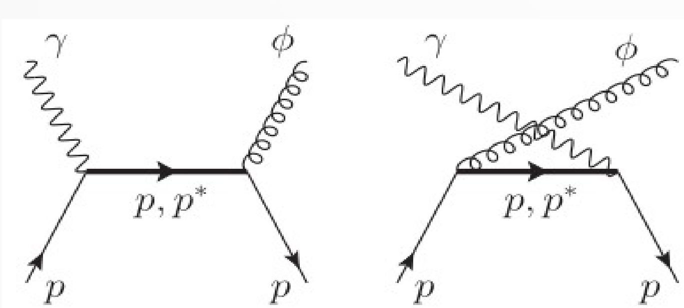
❑ Scattering amplitude: $T_{\phi N,\gamma N}(E) = [B_{\phi N,\gamma N} + T^{FSI}_{\phi N,\gamma N}(E)]$



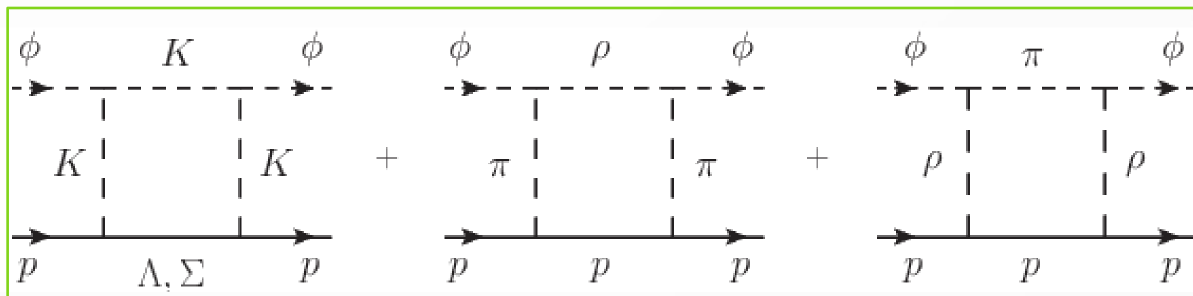
+







FSI=

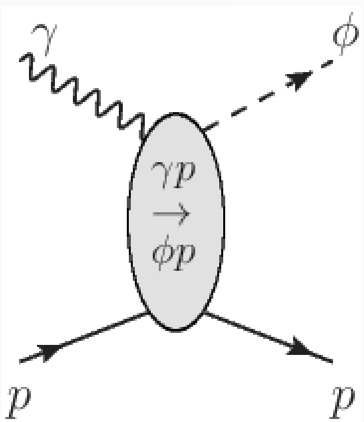


□ decay mode of φ-meson

Γ_1	K^+K^-	$(49.2 \pm 0.5)\%$
Γ_2	$K^0_L\ K^0_S$	$(34.0 \pm 0.4)\%$
Γ_3	$\rho\pi + \pi^+\pi^-\pi^0$	$(15.24 \pm 0.33)\%$
Γ_4	$\rho\pi$	
Γ_5	$\pi^+\pi^-\pi^0$	
Γ_6	$\eta\gamma$	$(1.303 \pm 0.025)\%$
Γ_7	$\pi^0\gamma$	$(1.32 \pm 0.06) \times 10^{-3}$
Γ_8	$\ell^+\ell^-$	
Γ_9	e^+e^-	$(2.974 \pm 0.034) \times 10^{-4}$
Γ_{10}	$\mu^+\mu^-$	$(2.86 \pm 0.19) \times 10^{-4}$
Γ_{11}	ηe^+e^-	$(1.08 \pm 0.04) \times 10^{-4}$
Γ_{12}	$\pi^+\pi^-$	$(7.3 \pm 1.3) \times 10^{-5}$
Γ_{13}	$\omega\pi^0$	$(4.7 \pm 0.5) \times 10^{-5}$
Γ_{14}	$\omega\gamma$	$< 5\%$
Γ_{15}	$\rho\gamma$	$< 1.2 \times 10^{-5}$

final state interaction (FSI)

❑ Scattering amplitude: $T_{\phi N,\gamma N}(E) = [B_{\phi N,\gamma N} + T^{FSI}_{\phi N,\gamma N}(E)]$



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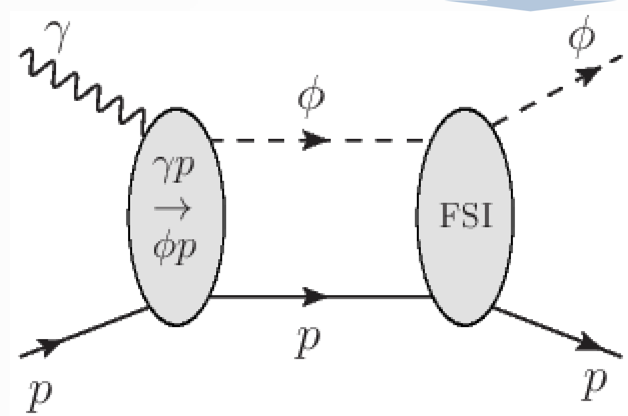
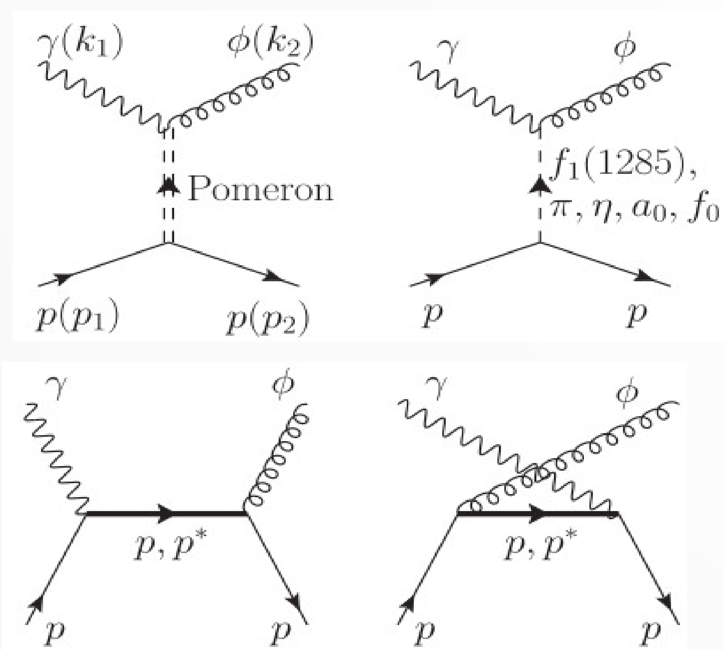
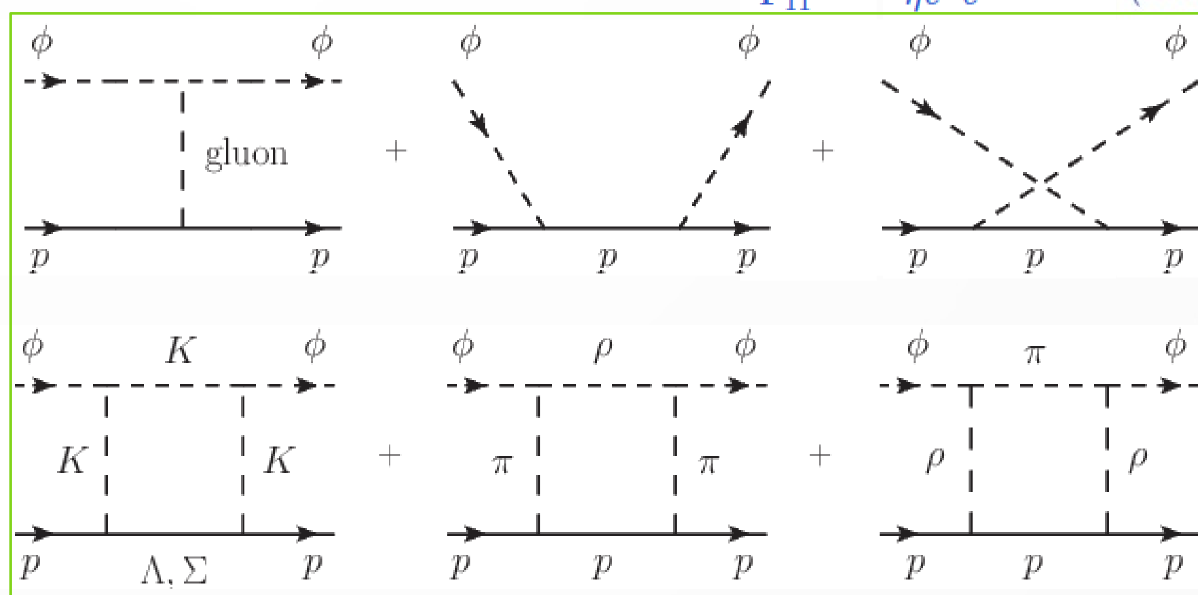




FSI=



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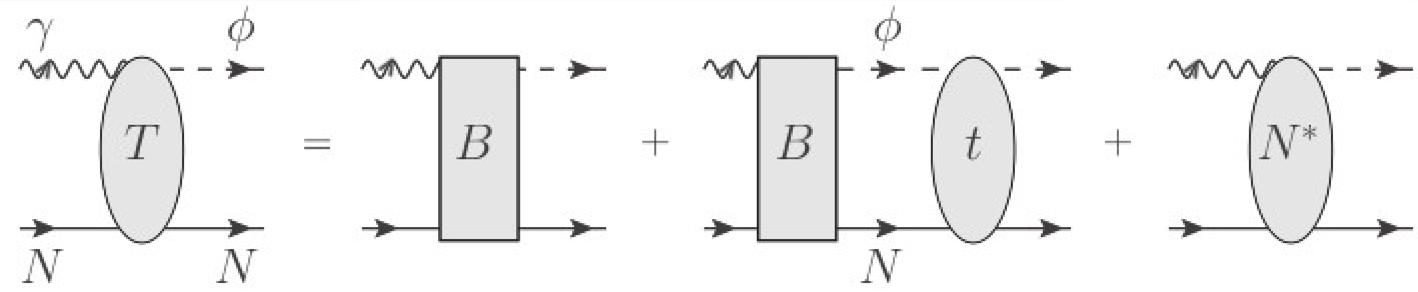
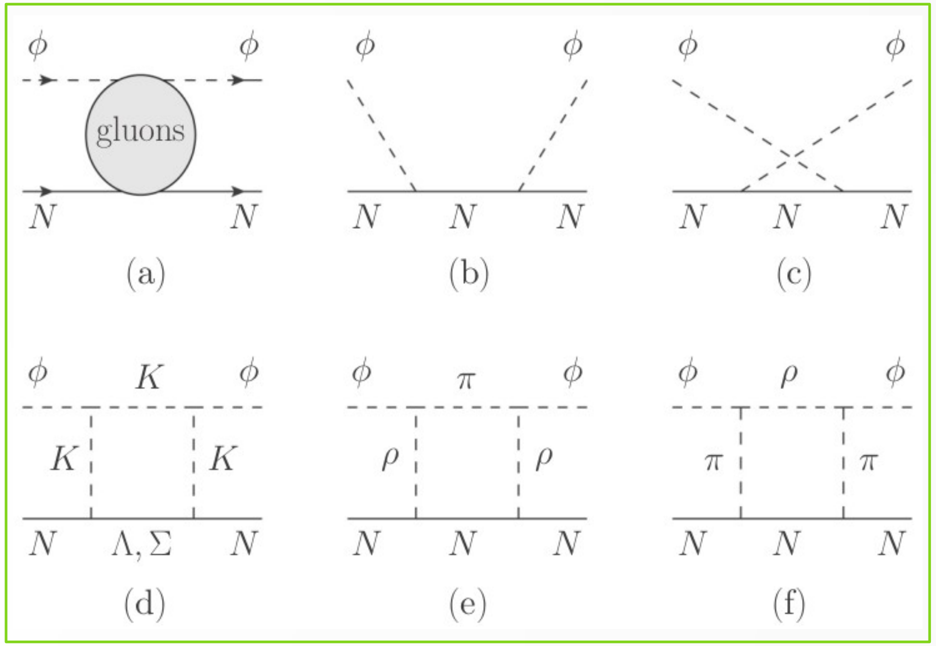
Γ_{11}	ηe^+e^-	$(1.08 \pm 0.04) \times 10^{-4}$
		$1.3) \times 10^{-5}$
		$0.5) \times 10^{-5}$
		$\times 10^{-5}$

Exclusive photoproduction of vector mesons

final state interaction (FSI)

$t_{\phi N,\phi N}(E)$

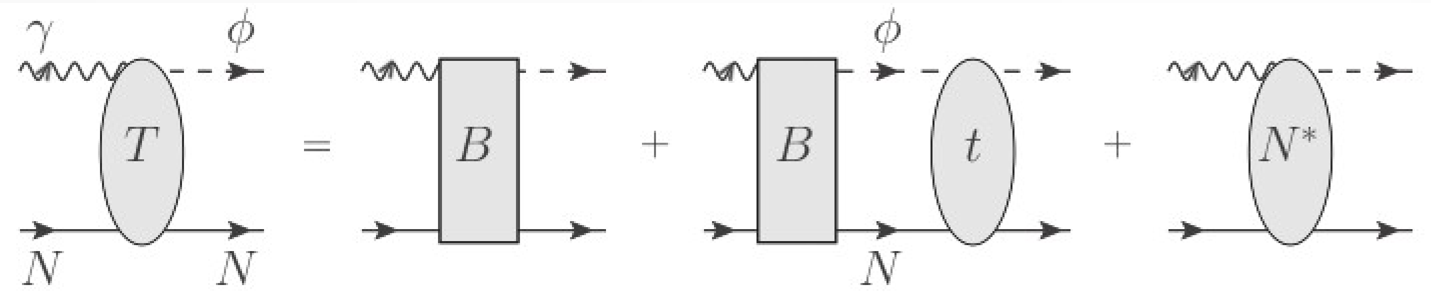




$$T_{\phi N,\gamma N}(E) = B_{\phi N,\gamma N} + T^{\mathrm{FSI}}_{\phi N,\gamma N}(E) + T^{N^*}_{\phi N,\gamma N}(E)$$

Exclusive photoproduction of vector mesons

final state interaction (FSI)



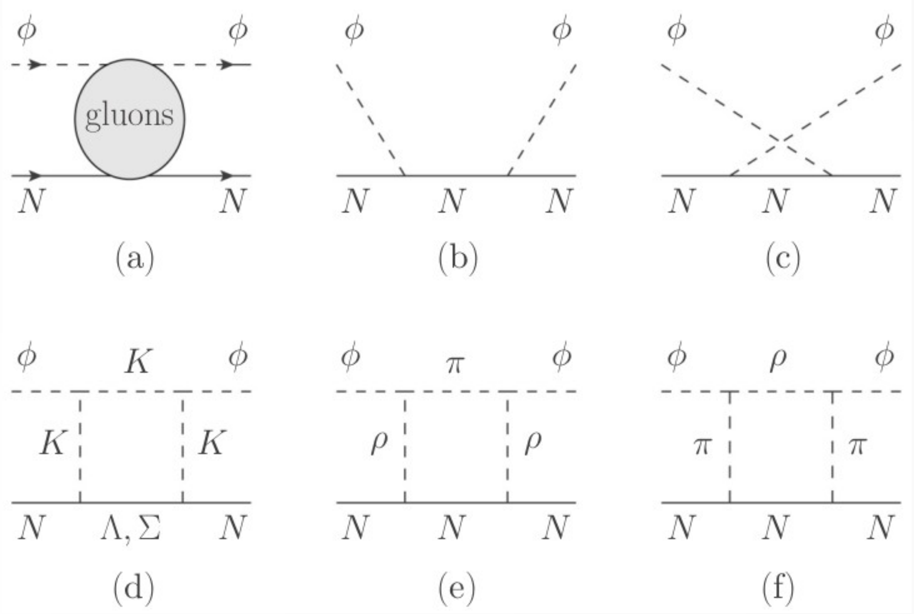
$$T_{\phi N,\gamma N}(E) = B_{\phi N,\gamma N} + T^{\mathrm{FSI}}_{\phi N,\gamma N}(E) + T^{N^*}_{\phi N,\gamma N}(E)$$

$$t_{\phi N,\phi N}(E) G_{\phi N}(E) B_{\phi N,\gamma N}$$

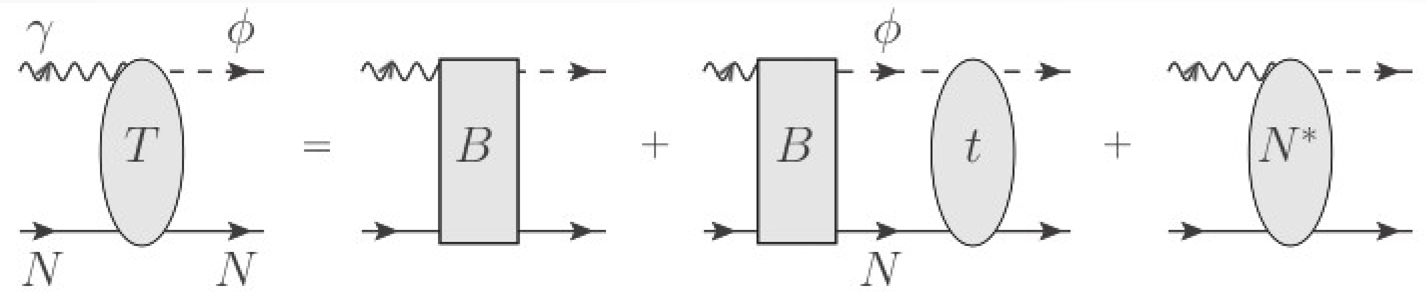
$$G_{MB}(E) = \frac{|MB\rangle \langle MB|}{E - H_0 + i\epsilon}$$: meson-baryon propagator

$$t_{\phi N,\phi N}(E) = V_{\phi N,\phi N}(E) + V_{\phi N,\phi N} G_{\phi N}(E) t_{\phi N,\phi N}(E)$$

$t_{\phi N,\phi N}(E)$



final state interaction (FSI)



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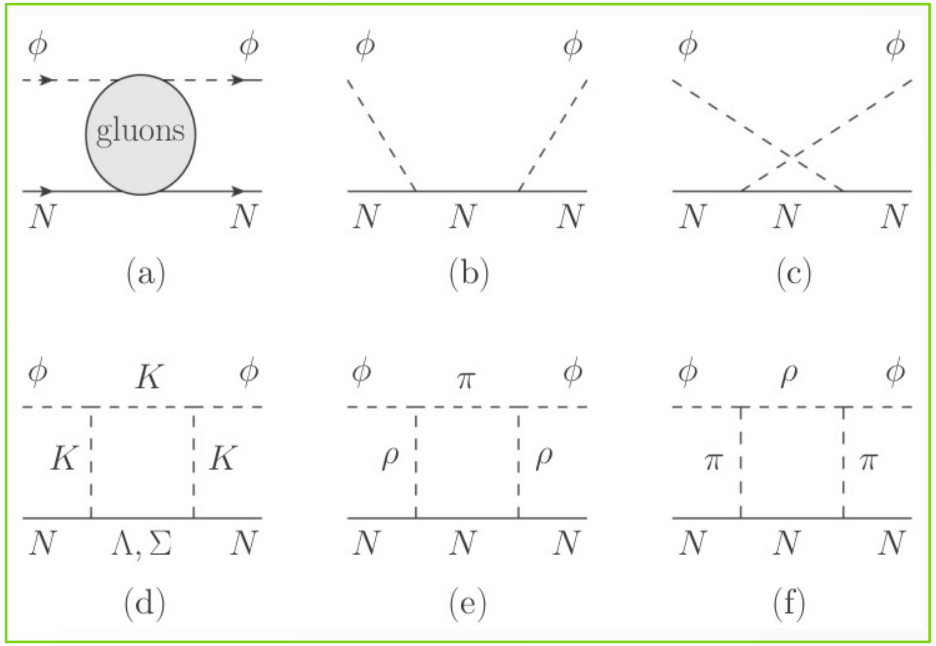
$$G_{MB}(E) = \frac{|MB\rangle\langle MB|}{E - H_0 + i\epsilon}$$: meson-baryon propagator

$$t_{\phi N,\phi N}(E) = V_{\phi N,\phi N}(E) + V_{\phi N,\phi N} G_{\phi N}(E) t_{\phi N,\phi N}(E)$$

$$v^{\mathrm{Gluon}}_{\phi N,\phi N} + v^{\mathrm{Direct}}_{\phi N,\phi N} + \sum_{MB} v_{\phi N,MB} G_{MB}(E) v_{MB,\phi N}$$

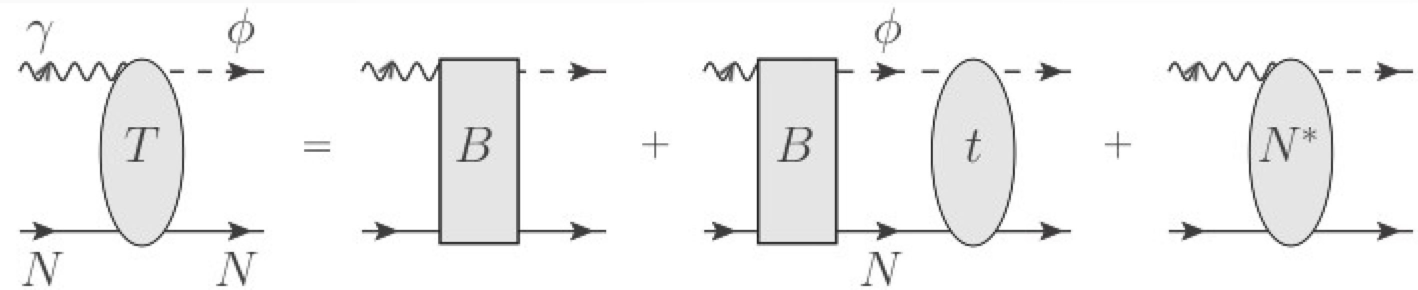
(a) (b,c) (d,e,f) MB = (KΛ, KΣ, πN, ρN)

$t_{\phi N,\phi N}(E)$



□ To leading order, we obtain these FSI diagrams.

final state interaction (FSI)



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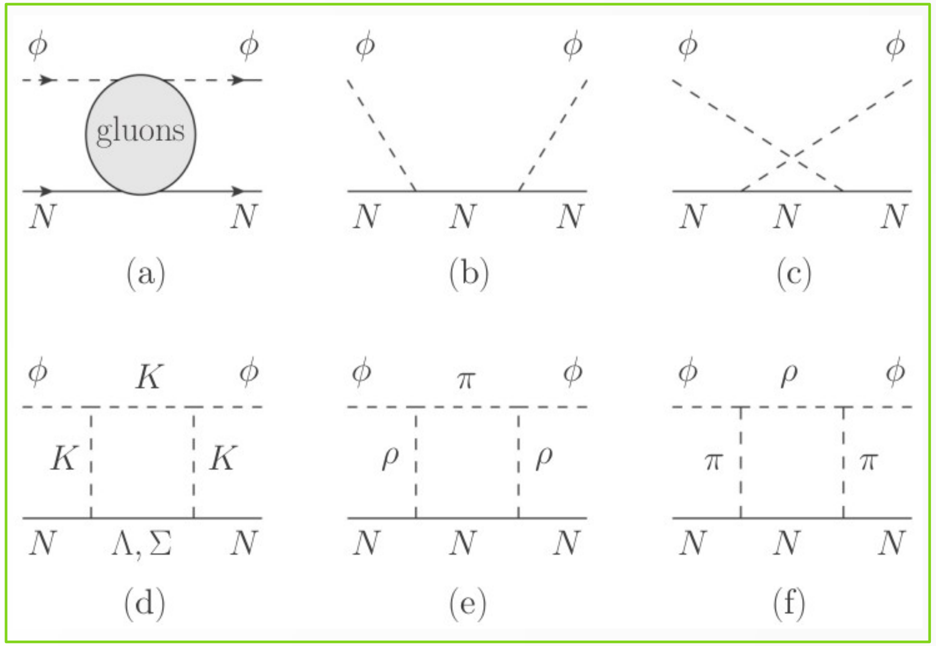
$$t_{\phi N,\phi N}(E) G_{\phi N}(E) B_{\phi N,\gamma N}$$

$t_{\phi N,\phi N}(E)$



$$G_{MB}(E) = \frac{|MB\rangle \langle MB|}{E - H_0 + i\epsilon}$$: meson-baryon propagator

$$\frac{1}{E - H_0 + i\epsilon} = P\frac{1}{E - H_0} - i\pi\delta(E - H_0)$$

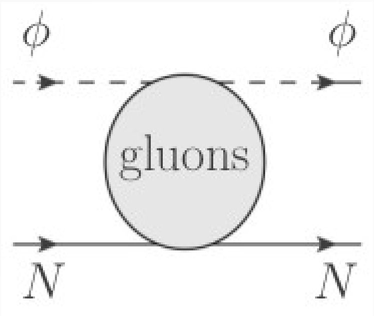
□ We consider both parts numerically.

$$t_{\phi N,\phi N}(E) = V_{\phi N,\phi N}(E) + V_{\phi N,\phi N} G_{\phi N}(E) t_{\phi N,\phi N}(E)$$

$$v^{\mathrm{Gluon}}_{\phi N,\phi N} + v^{\mathrm{Direct}}_{\phi N,\phi N} + \sum_{MB} v_{\phi N,MB} G_{MB}(E) v_{MB,\phi N}$$

(a) (b,c) (d,e,f) MB = (KΛ, KΣ, πN, ρN)

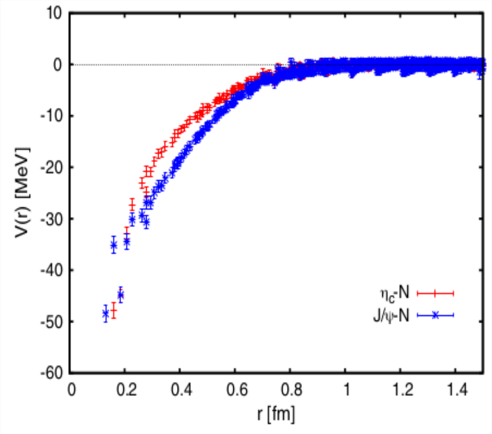
final state interaction (FSI)



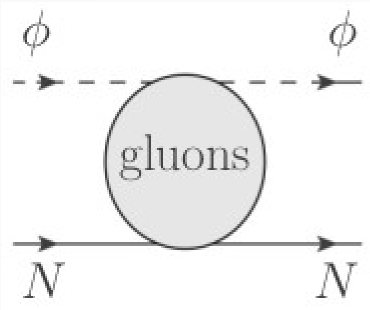
- The J/ψ-N potential from the LQCD data ~ Yukawa form ($\upsilon_0 = 0.1$, $\alpha = 0.3$ GeV)
  [Kawanai, Sasaki, PRD.82.091501(R) (2010)]

$$\mathcal{V}_{\text{gluon}} = -\upsilon_0 \frac{e^{-\alpha r}}{r}$$

- which is assumed in our work, φ-N potential
  The best fit was obtained by ($\upsilon_0 = 0.2$, $\alpha = 0.5$ GeV).



final state interaction (FSI)



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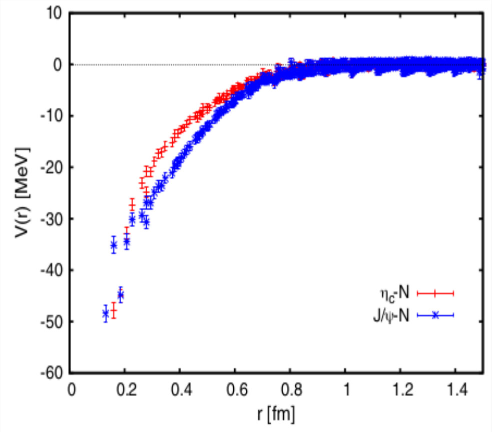


❑ which is assumed in our work, φ-N potential
The best fit was obtained by (υ_0 = 0.2, α = 0.5 GeV).

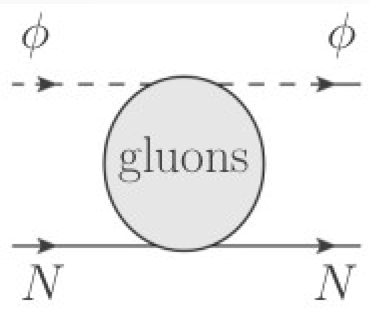
❑ The potential is obtained by taking the nonrelativistic limit of the scalar-meson exchange amplitude calculated from the Lagrangian:

$$\mathscr{L}_\sigma = V_0(\bar{\psi}_N \psi_N \Phi_\sigma + \phi^\mu \phi_\mu \Phi_\sigma)$$

Φ_σ is a scalar field with mass α ($V_0=-8\upsilon_0\pi M_\varphi$).

❑ $$\mathcal{V}_{\rm gluon}(k\lambda_\phi, pm_s; k'\lambda'_\phi, p'm'_s) = \frac{V_0}{(p-p')^2-\alpha^2}[\bar{u}_N(p,m_s)u_N(p',m'_s)][\epsilon^*_\mu(k,\lambda_\phi)\epsilon^\mu(k',\lambda'_\phi)]$$

final state interaction (FSI)



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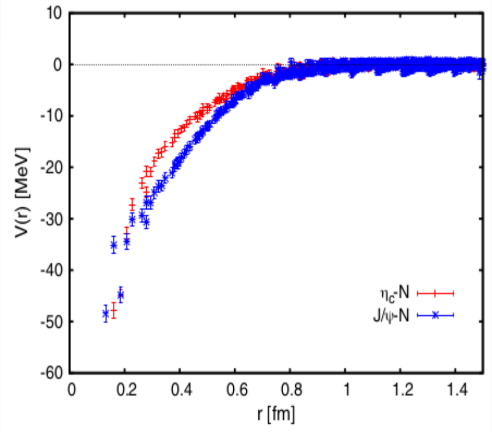


- which is assumed in our work, φ-N potential
  The best fit was obtained by ($\upsilon_0 = 0.2$, $\alpha = 0.5$ GeV).

- The φ-N potential from the LQCD [hep-lat] 2205.10544

Attractive N-ϕ Interaction and Two-Pion Tail from Lattice QCD near Physical Point

Yan Lyu,[1,2,*] Takumi Doi,[2,†] Tetsuo Hatsuda,[2,‡] Yoichi Ikeda,[3,§]
Jie Meng,[1,4,¶] Kenji Sasaki,[3,**] and Takuya Sugiura[2,††]

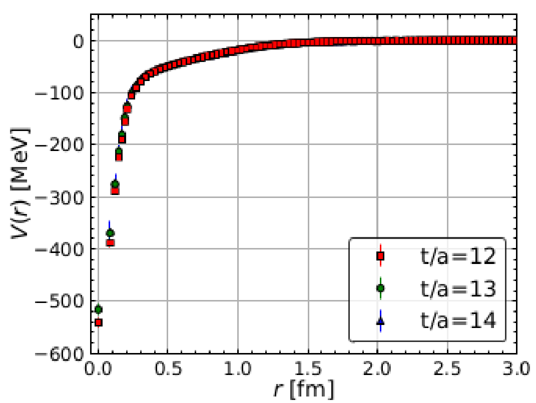


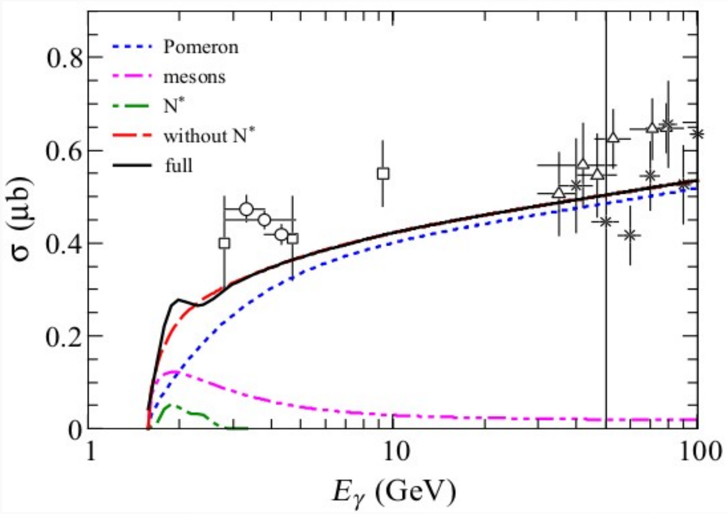
FIG. 1. (Color online). The N-ϕ potential $V(r)$ in the $^4S_{3/2}$ channel as a function of separation r at Euclidean time t/a = 12 (red squares), 13 (green circles) and 14 (blue triangles).

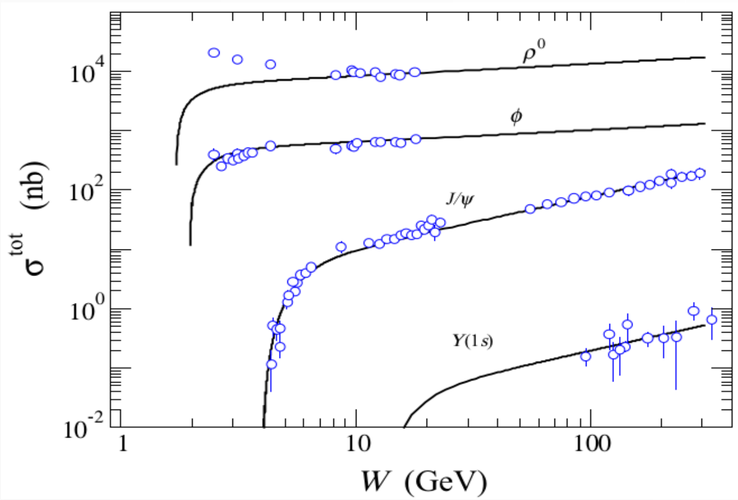
- The simple fitting functions such as
  "the Yukawa form" and "the van der Waals form ~ $1/r^k$ with k=6(7)"
  cannot reproduce the lattice data.

> We need to update our results based on the LQCD data.

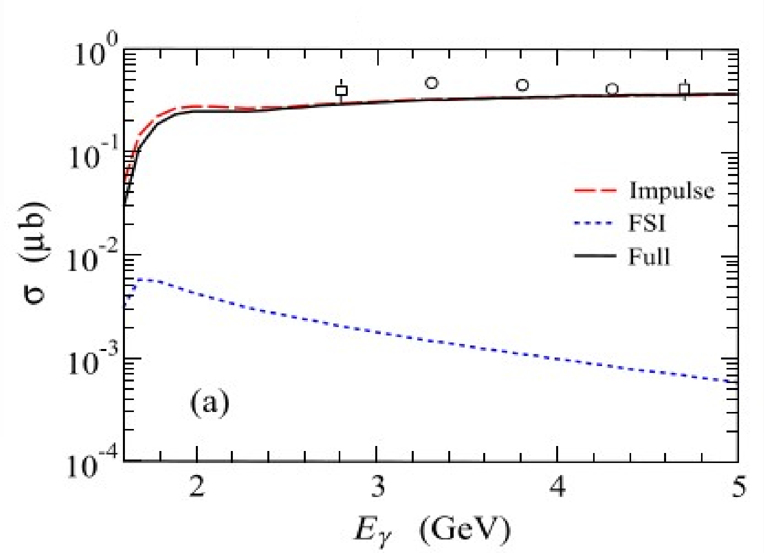
Exclusive photoproduction of vector mesons [results]

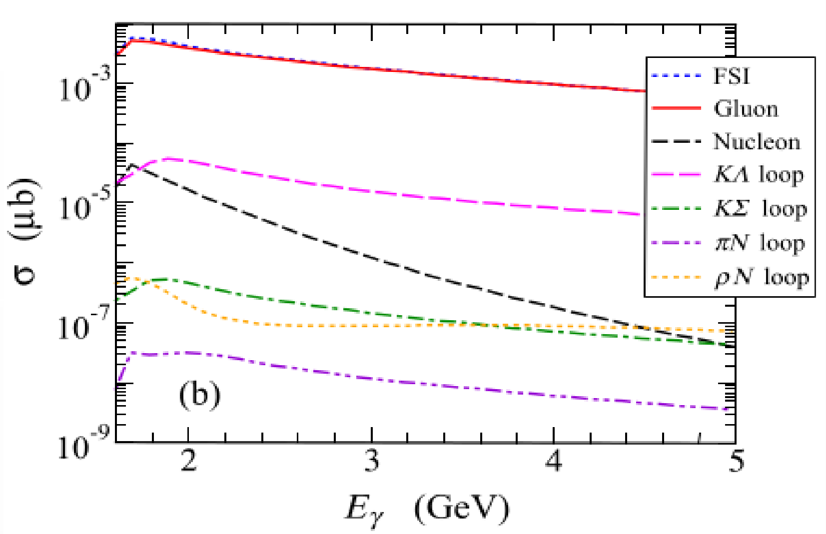
Born term total cross section [$\gamma\, p \to \varphi\, p$] with FSI





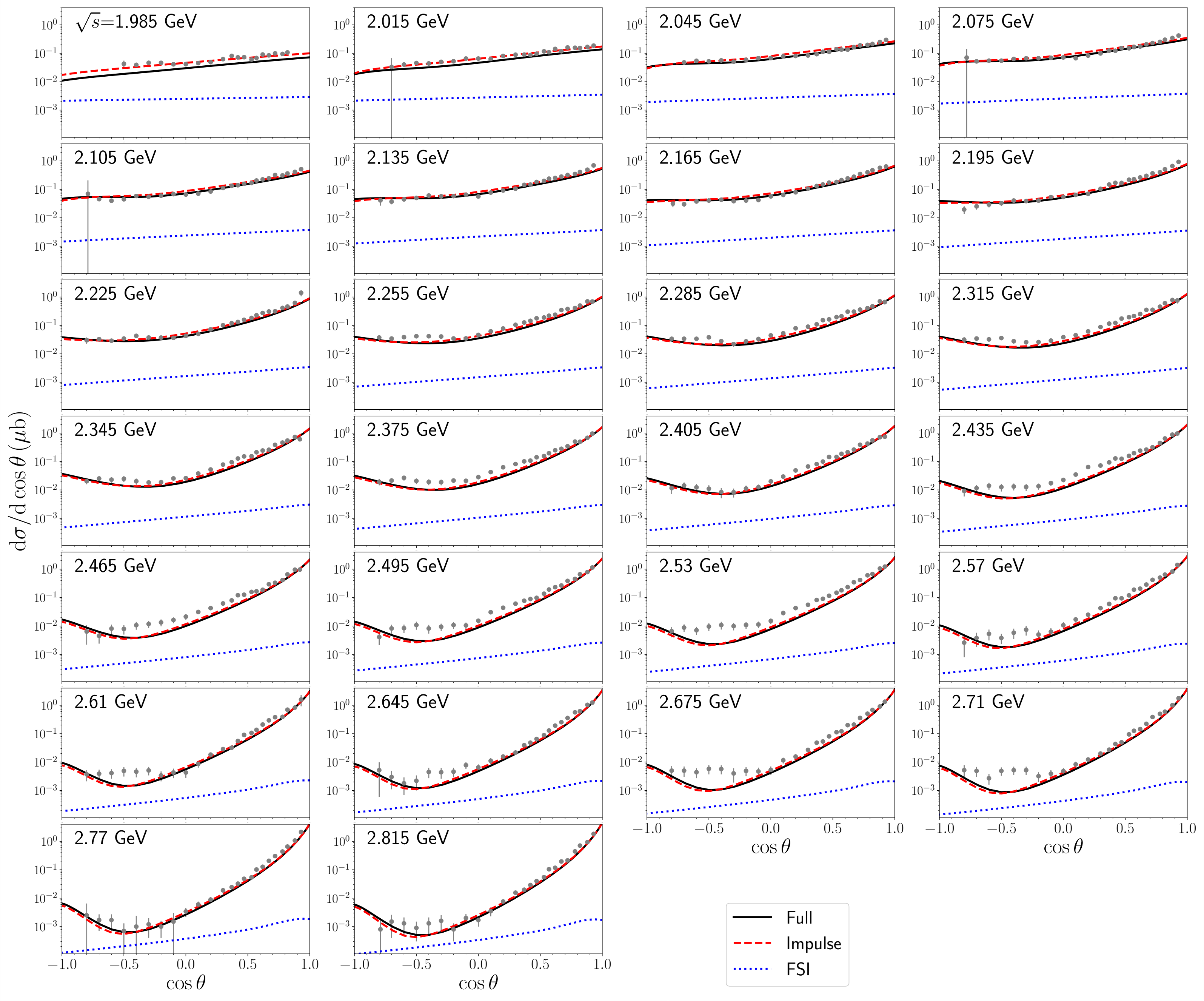
$\gamma\, p \to$
ρ^0
ω
φ
J/ψ
$\Upsilon(1s)$





- Our Pomeron model describes the high energy regions quite well.
- The contributions of the FSI terms are almost very small.

Exclusive photoproduction of vector mesons [results]



differential cross sections
[γ p → φ p]

with FSI

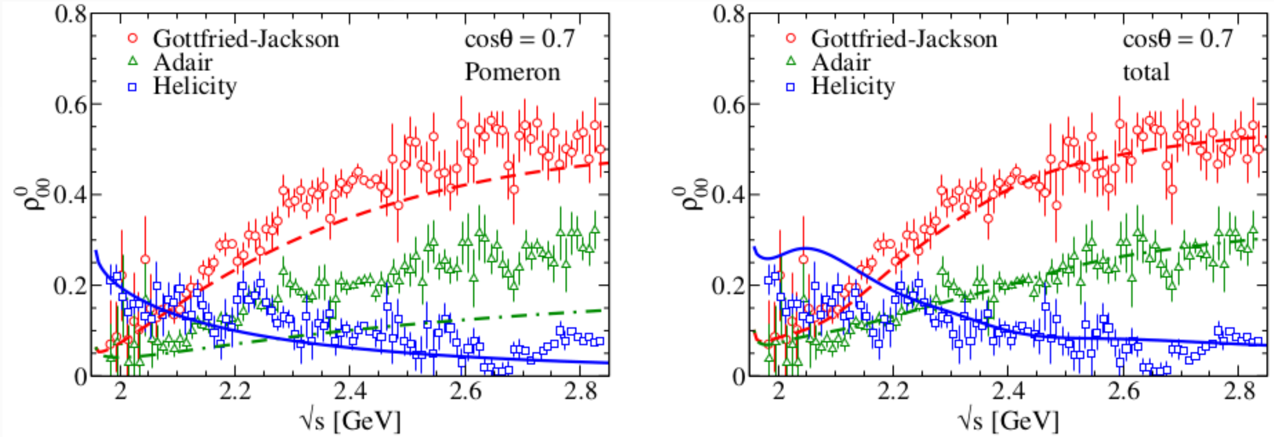
- ☐ The contributions of the FSI terms are very small.

[Exp: Dey (CLAS), PRC.89. 055208 (2014)]

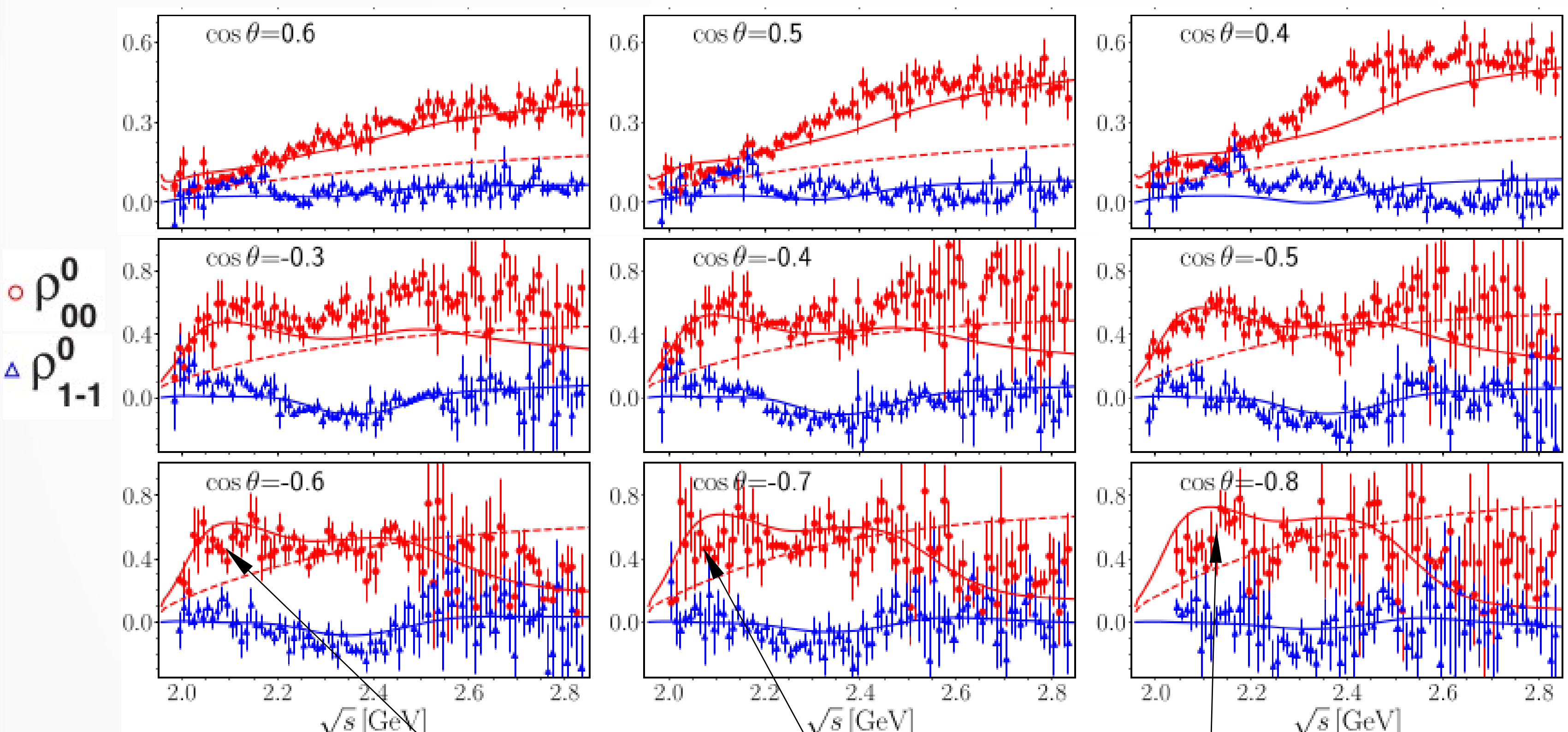
Exclusive photoproduction of vector mesons [results]

spin-density matrices

[$\gamma\, p \to \varphi\, p$]



- TCHC & SCHC are broken.



full

Pomeron

full

Adair frame

$N^*(2000,5/2^+)$ & $N^*(2300,1/2^+)$

[Exp: Dey (CLAS), PRC.89. 055208 (2014)]

Summary & Future work

◇ For $\gamma\, p \to \varphi\, p$ & $\gamma^*\, p \to \varphi\, p$, we studied the relative contributions between the Pomeson and various meson exchanges.
The light-meson (π, η, a_0, f_0,...) contribution is crucial to describe the data at low energies.

◇ Extension to $\gamma^{(*)}\, A \to V[\varphi, J/\psi, \Upsilon(1S)]\, A$, [$A = {}^2H, {}^4He, {}^{12}C, \ldots$]
$\gamma\, {}^4He \to \varphi\, {}^4He$ [S.H.Kim, T.S.H.Lee, S.i.Nam, Y. Oh, PRC.104.045202 (2021)]
> A distorted-wave impulse approximation within the multiple scattering formulation

◇ Approved 12 GeV era experiments to date at Jafferson Labarotory:
[E12-09-003] Nucleon Resonances Studies with CLAS
[E12-11-002] Proton Recoil Polarization in the ${}^4He(e,e'p){}^3H$, ${}^2He(e,e'p)n$, ${}^1He(e,e'p)$
[E12-11-005] Meson spectroscopy with low Q^2 electron scattering in CLAS12
[E12-12-006] Near Threshold Electroproduction of J/ψ at 11 GeV
[E12-12-007] Exclusive Phi Meson Electroproduction with CLAS12

◇ Electron-Ion Collider (EIC) will carry out the relevant experiments in the future.

Summary & Future work

◇ Production of multistrangeness (S < -1) baryons

$K^- p \rightarrow K^- p$ ➪ $K^- \, ^{12}C \rightarrow K^- \, ^{12}C$

$K^- p \rightarrow K^+ \Xi$ ➪ $K^- \, ^{12}C \rightarrow K^+ \, ^{12}_{\Xi}Be$

> A distorted-wave impulse approximation within the multiple scattering formulation

> Ξ hypernuclei is important to study multistrangeness systems and strange neutron stars in astrophysics.

◇ Relevant experiments to date at J-PARC:

[P05] Spectroscopic Study of Ξ-Hypernucleus, $^{12}_{\Xi}Be$, via the $^{12}C(K^-,K^+)$ Reaction

[P85] Spectroscopy of Omega Baryons

[LoI] Study of Σ-N interaction using light Σ-nuclear system

[LoI] Ξ Baryon Spectroscopy High-momentum Secondary Beam

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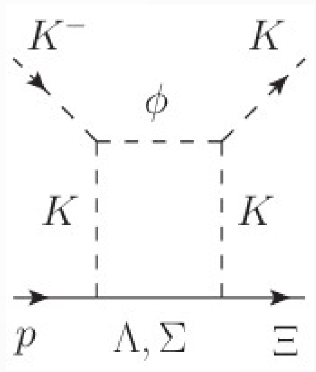
◇ Rescattering effects could be important for the meson induced production:

$K^- p \rightarrow K^+ \Xi$, $\pi^- p \rightarrow \varphi n$,

$K^- p \rightarrow \varphi (\Lambda,\Sigma)$, $\pi^- p \rightarrow D^- (\Lambda_c,\Sigma_c)$

> The systematic analyses should be carried out.



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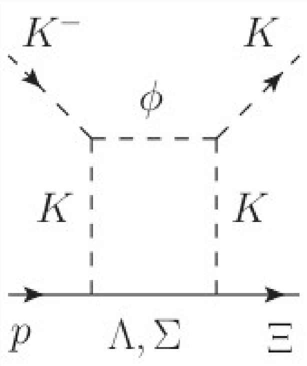

Thank you very much for your attention