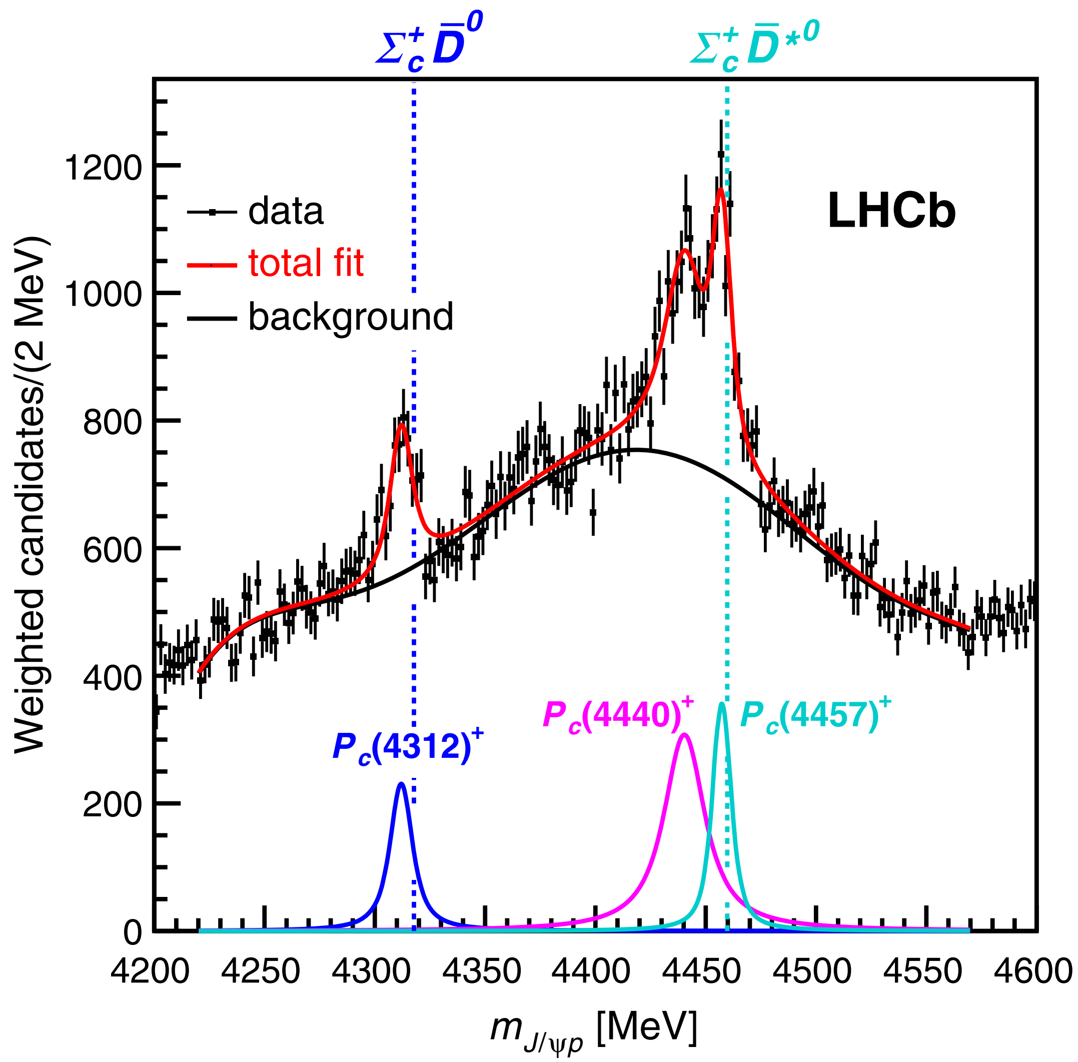
Photoproduction of ϕ-meson with K*Σ-bound state

Sang-In SHIM (沈　相仁)

19th December 2023

Collaborated with Prof. Yongsun Kim and Seung-il Nam

Background and motivation



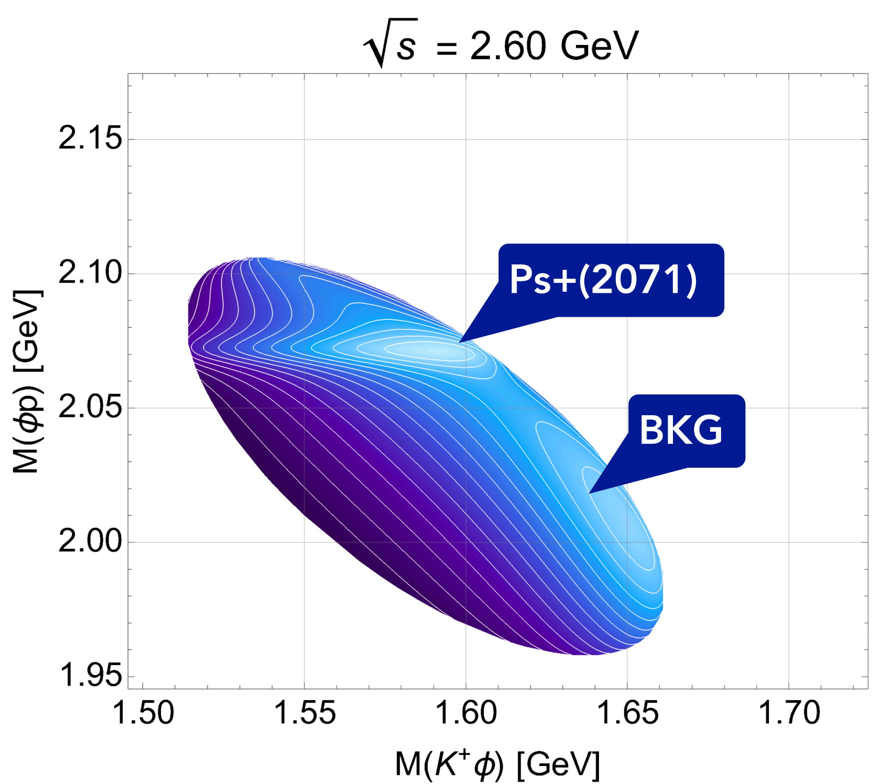
LHCb experiment confirmed P_c

$P_c^+[\bar{D}^*\Sigma_c]$ —> $J/\psi[c\bar{c}]p$

—>confirmed!

$P_s^+[K^*\Sigma]$ —> $\phi[s\bar{s}]p$

—>possible?



Attempt to find P_s from $K^+p \rightarrow K^+\phi p$

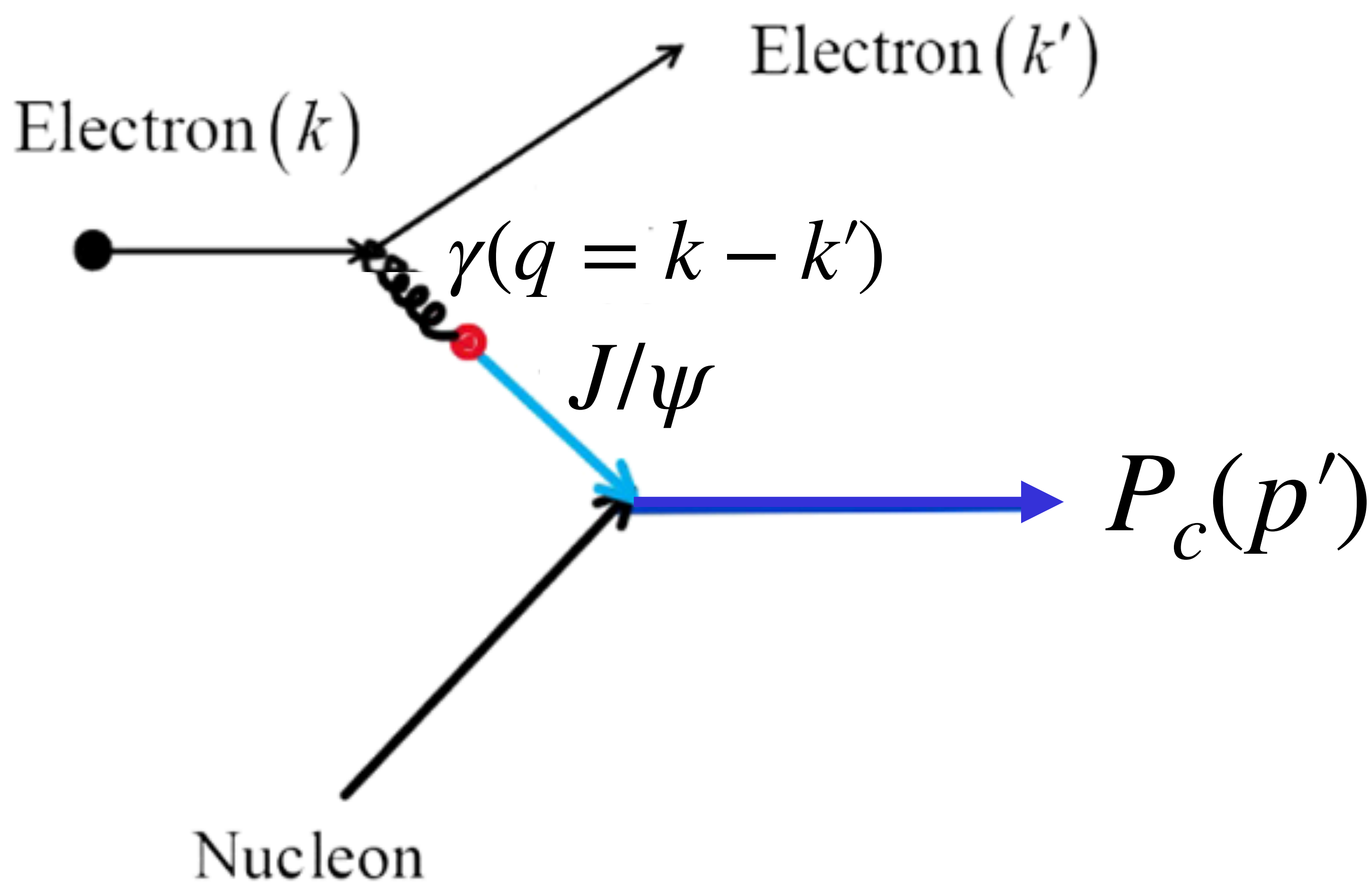
by Prof. S.-i Nam PRD103, 054040(2021)

Background and motivation

PHYSICAL REVIEW D **105**, 114023 (2022)

Production of $P_c(4312)$ state in electron-proton collisions

In Woo Park,[1] Sungtae Cho,[2,3] Yongsun Kim,[4,3,*] and Su Houng Lee[1,†]



Electroproduction of J/ψ with P_c

Photo- or electroproduction of ϕ-meson with P_s ?

Similar process for P_s is also possible

Pentaquark molecular K*Σ bound-state P_s (2071, $3/2^-$)

PHYSICAL REVIEW D **83,** 114041 (2011)

Vector meson-baryon dynamics and generation of resonances

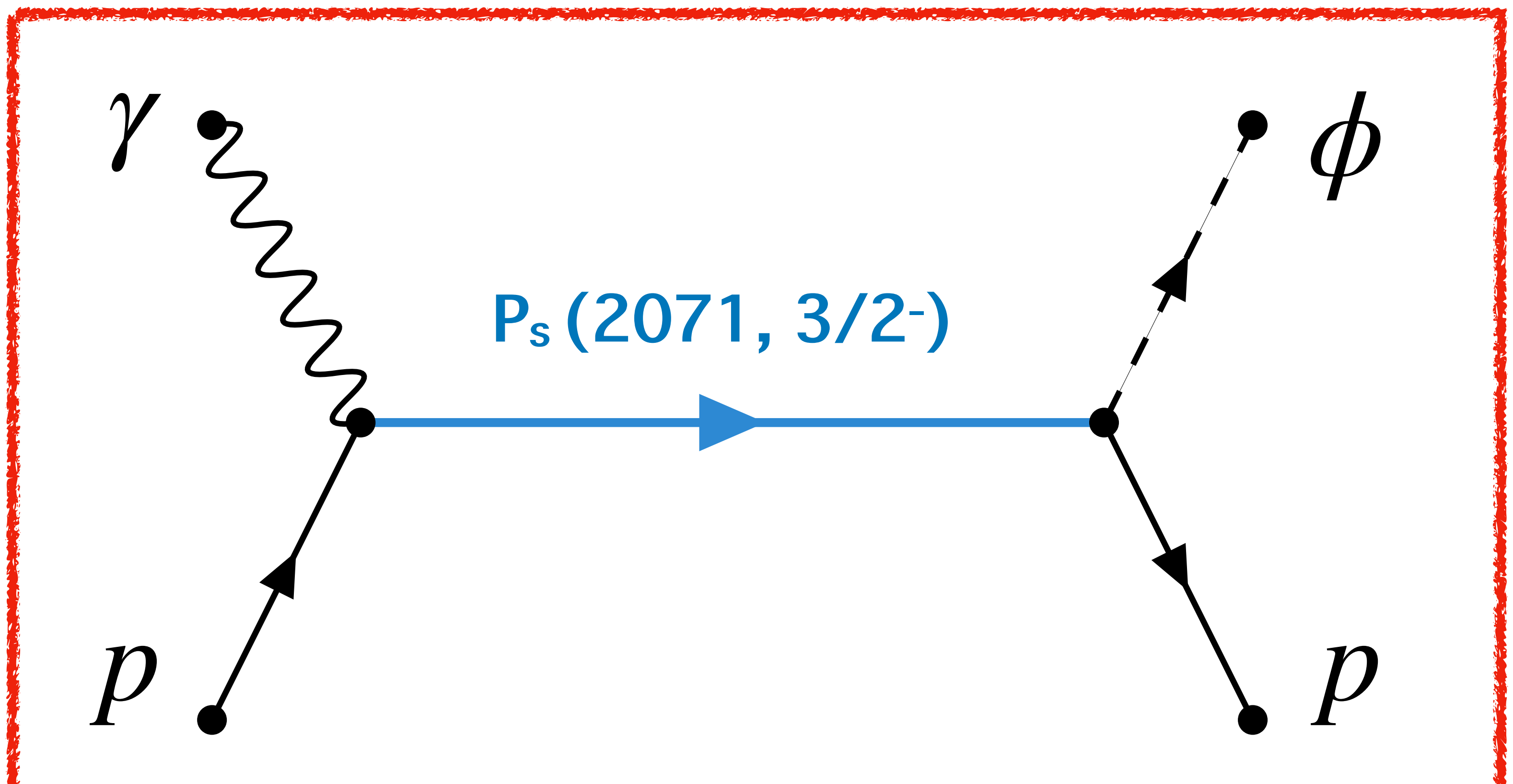
K. P. Khemchandani,[1,*] H. Kaneko,[1,†] H. Nagahiro,[2,‡] and A. Hosaka[1,§]
[1]*Research Center for Nuclear Physics (RCNP), Mihogaoka 10-1, Ibaraki 567-0047, Japan*
[2]*Department of Physics, Nara Women's University, Nara 630-8506, Japan*
(Received 15 April 2011; published 22 June 2011)

The purpose of this work is to study vector meson-octet baryon interactions with the aim to find dynamical generation of resonances in such systems. For this, we consider *s*-, *t*-, *u*-channel diagrams along with a contact interaction originating from the hidden local symmetry Lagrangian. We find the contribution from all these sources, except the *s* channel, to be important. The amplitudes obtained by solving coupled channel Bethe-Salpeter equations for systems with total strangeness zero, show the generation of one isospin 3/2, spin 1/2 resonance and three isospin 1/2 resonances: two with spin 3/2 and one with spin 1/2. We identify these resonances with $\Delta(1900)S_{31}$, $N^*(2080)D_{13}$, $N^*(1700)D_{13}$, and $N^*(2090)S_{11}$, respectively.

Strongly couple to ϕ p

$P_s \rightarrow \phi$ p is expected

(Similar to $P_c \rightarrow J/\psi$ p)



We will investigate photo- and electroproduction including P_s

Theoretical formalism

Vector meson dominance (VMD) and Lagrangians for P_s

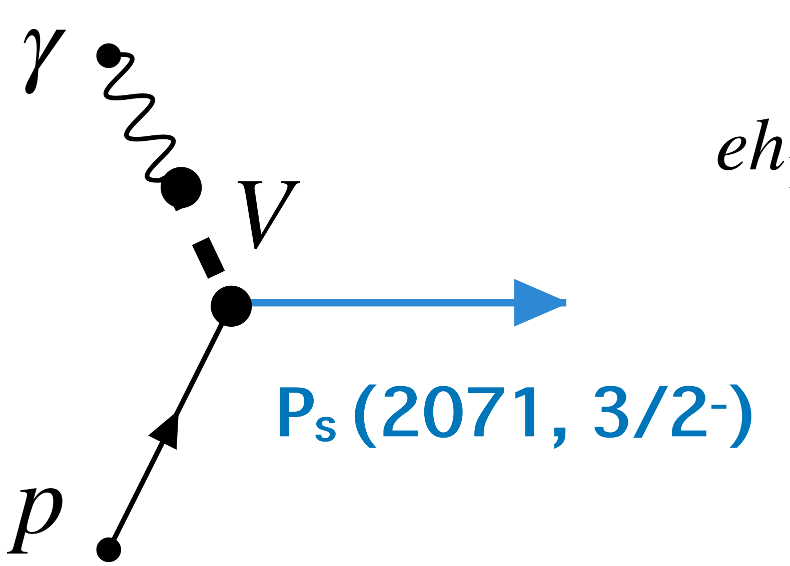
$$\mathscr{L}_{\gamma NP_s} = e\left(\frac{ih_1}{2m_N}\bar{N}\gamma^\nu - \frac{h_2}{(2m_N)^2}\partial^\nu \bar{N}\right)F_{\mu\nu}P_s^\mu + H.c. + H.c.$$

$$\mathscr{L}_{VNP_s} = -\frac{ig_1}{2m_N}\bar{N}\gamma^\nu F^V_{\mu\nu}P_s^\mu - \frac{g_2}{(2m_N)^2}\partial^\nu \bar{N}F^V_{\mu\nu}P_s^\mu + \frac{g_3}{(2m_N)^2}\bar{N}\partial^\nu F^V_{\mu\nu}P_s^\mu + H.c.$$

Here, we consider only the leading terms

g_1 and $\Gamma_{P_s} = 14\ \mathrm{MeV}$ K. P. Khemchandani et al. PRD**83**.114041(2011)

Using VMD,



$$eh_1 = g_1 \frac{e}{f_V}\frac{2m_N(m_N + m_{P_s})}{(m_{P_s^2} - m_N^2)m_V}\sqrt{\frac{6m_V^2 m_{P_s}^2 + m_N^4 - 2m_N^2 m_{P_s}^2 + m_{P_s}^4}{3m_{P_s}^2 + m_N^2}}$$

Xiao-Yun Wang et al. PRD99, 114007(2019)

vector meson decay constant f_V

J.-J. Wu and T. S. H. Lee PRC**86. 065203 (2012)**

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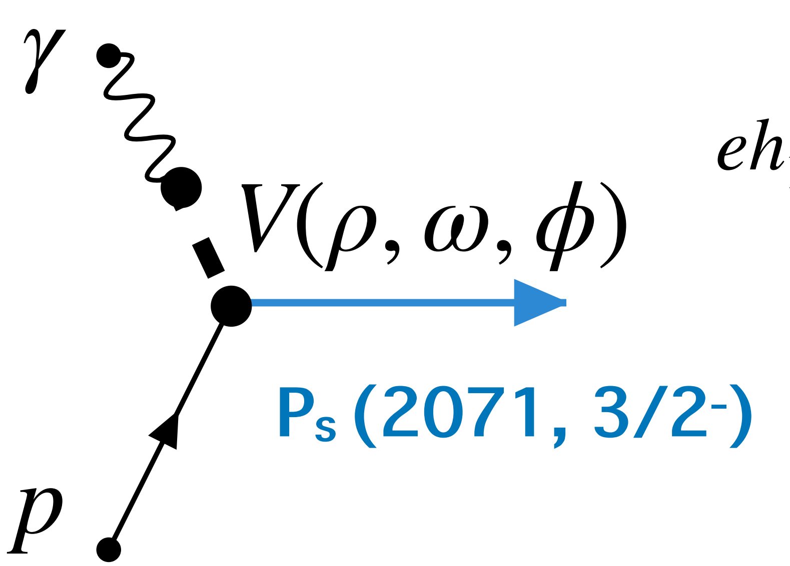
Here, we consider only the leading terms

g_1 and $\Gamma_{P_s} = 14$ MeV

K. P. Khemchandani et al. PRD**83**.114041(2011)

$M_R - i\Gamma/2 \to (J^\pi)$	2071 − i7 MeV $(3/2^-)$
Channels ↓	Couplings (g^i)
ρN	$0.02 - i0.4$
ωN	$-0.1 - i0.1$
ϕN	$0.14 + i0.2$
$K^*\Lambda$	$-0.3 + i0.35$
$K^*\Sigma$	$2.4 + i0.3$

Using VMD,



$$eh_1 = g_1\frac{e}{f_V}$$

Theoretical formalism

Vector meson dominance (VMD) and Lagrangians for P_s

$$\mathcal{L}_{\gamma NP_s} = e\left(\frac{ih_1}{2m_N}\bar{N}\gamma^\nu - \frac{h_2}{(2m_N)^2}\partial^\nu\bar{N}\right)F_{\mu\nu}P_s^\mu + H.c. + H.c.$$

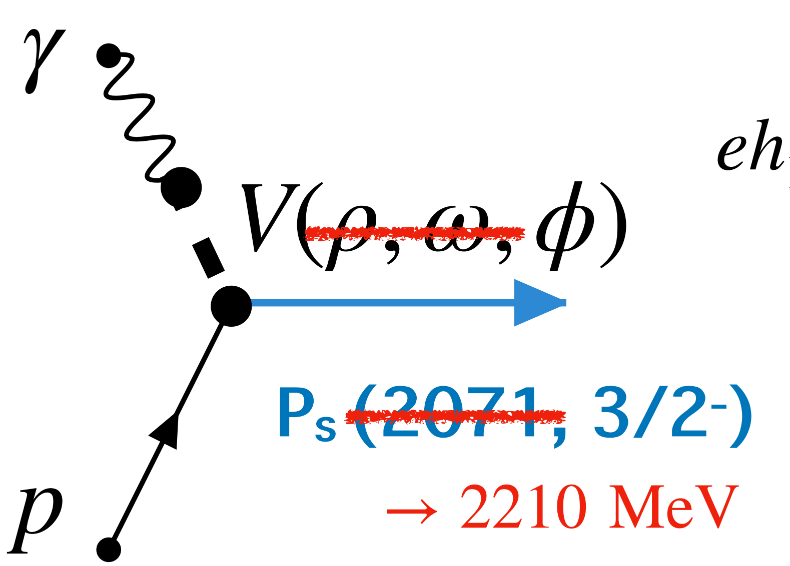
$$\mathcal{L}_{VNP_s} = -\frac{ig_1}{2m_N}\bar{N}\gamma^\nu F^V_{\mu\nu}P_s^\mu - \frac{g_2}{(2m_N)^2}\partial^\nu\bar{N}F^V_{\mu\nu}P_s^\mu + \frac{g_3}{(2m_N)^2}\bar{N}\partial^\nu F^V_{\mu\nu}P_s^\mu + H.c.$$

Here, we consider only the leading terms Include only ϕ-meson to explain exp. data

g_1 and Γ_{P_s} = ~~14 MeV~~ $\rightarrow$ 28 MeV

K. P. Khemchandani et al. PRD**83**.114041(2011)

Using VMD,



$$eh_1 = g_1\frac{e}{f_V}$$

$M_R - i\Gamma/2 \rightarrow (J^\pi)$	2071 − i7 MeV ($3/2^-$)
Channels ↓	Couplings (g^i)
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ϕN	0.14 + i0.2
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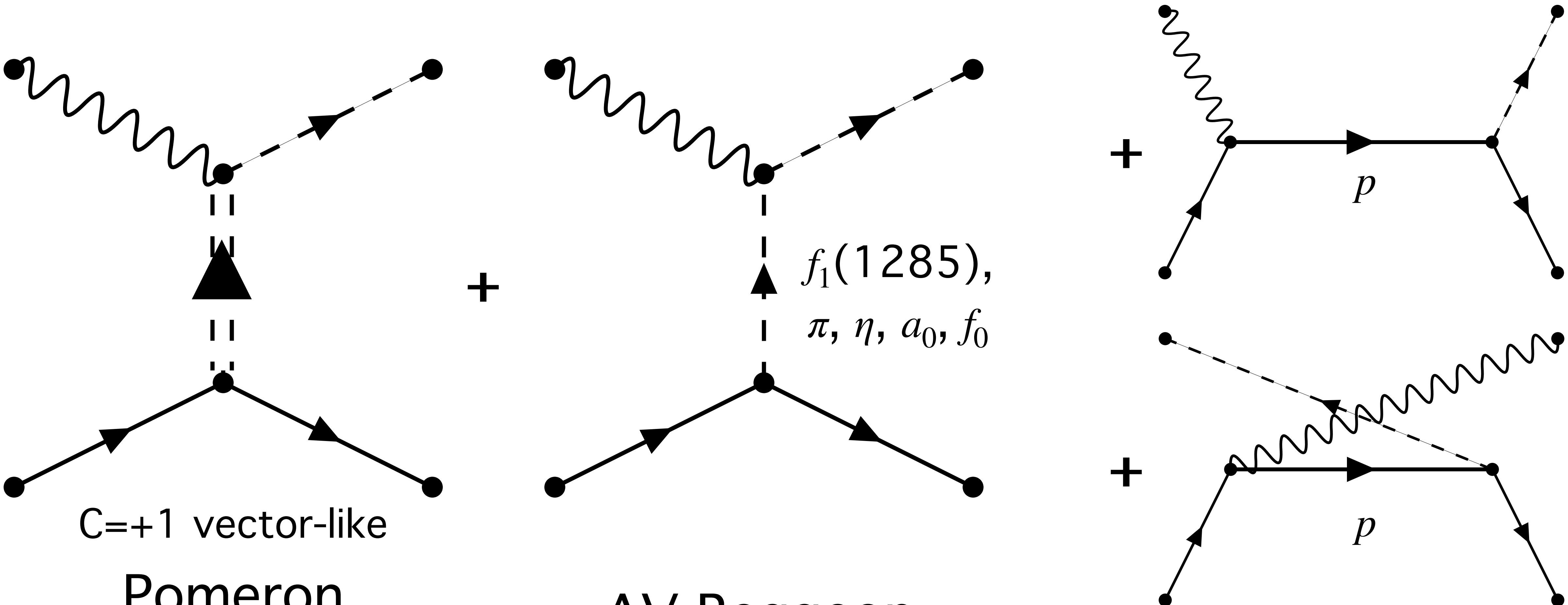
Other contributions for ϕ-photoproduction[1,2]



Pomeron

Most dominant

AV Reggeon,
PS, S t-channel

Nucleon and resonances

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

- All contributions satisfy Ward-Takahashi identity
- Here, we consider only two nucleon resonances

[1] A. I. Titov et al. PRC58, 2429(1998); 67, 065205(2003)
[2] Sang-ho Kim, Seung-il Nam PRC100.065208(2019); 101.065201(2020)

Unknown parameters (phases & cutoffs)

Phase factor $e^{i\pi\beta}$ β : relative phase ($\beta_{\mathbb{P}} = 0$)

Form factors

$$F_{\text{meson}} = \frac{\Lambda_{\text{meson}}^2 - M_{\text{meson}}^2}{\Lambda_{\text{meson}}^2 - t} \qquad F_{N,s(u)} = \frac{\Lambda_N^4}{\Lambda_N^4 + \left(s(u) - M_N^2\right)^2}$$

TABLE I

	f_1	PS	S	N	$N^*(2000, \frac{5}{2}^+)$	$N^*(2300, \frac{1}{2}^+)$	P_s
phase β	1	0	3/2	1	1	1/2	1
[1,2] cutoff Λ (GeV)	1.5	0.87	1.35	1.0	1.0	1.0	1.0

[1]A. I. Titov et al. PRC58, 2429(1998); 67, 065205(2003)

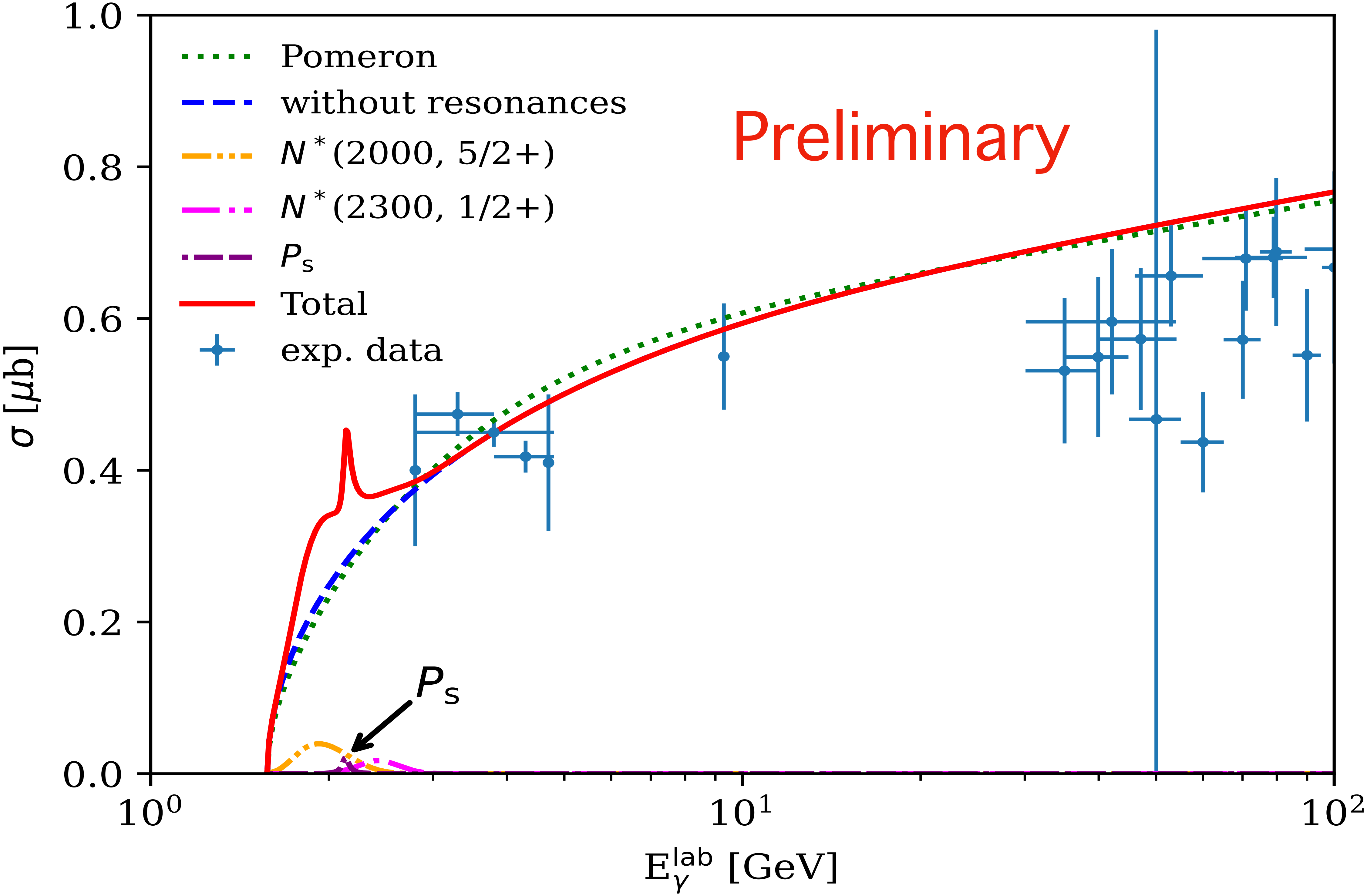
[2]Sang-ho Kim, Seung-il Nam PRC100.065208(2019); 101.065201(2020)

Result

compared with exp.

J. Ballam et al. PRD 7, 3150 (1973)
D. P. Barber et al., Z. Phys. C 12, 1 (1982)
R. M. Egloff et al., PRL **43**, 657(1979)
J. Busenitz et al., PRD 40, 1 (1989)

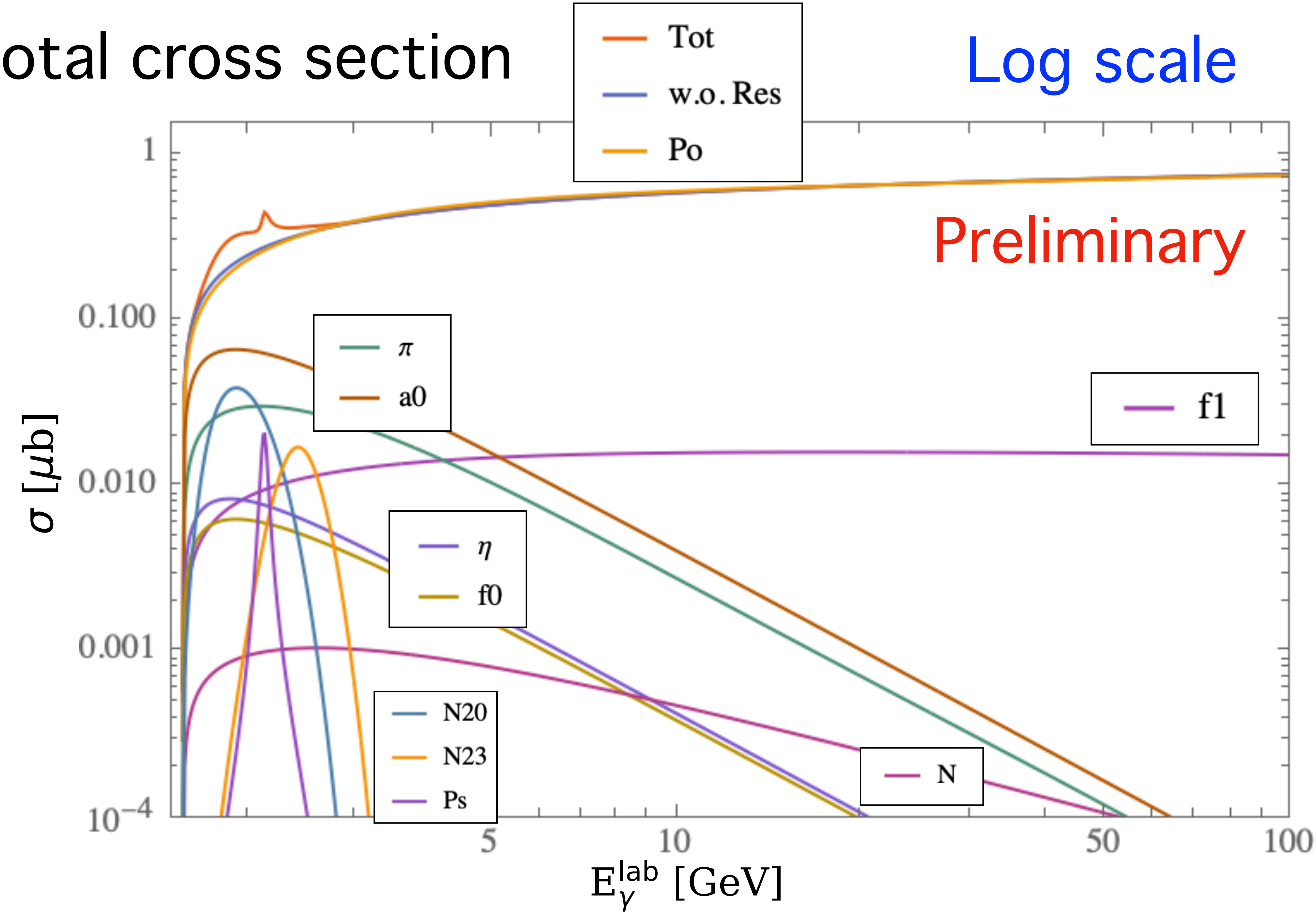
Total cross section



- **The exp. data** can be explained by **the Pomeron alone**

Result

Total cross section



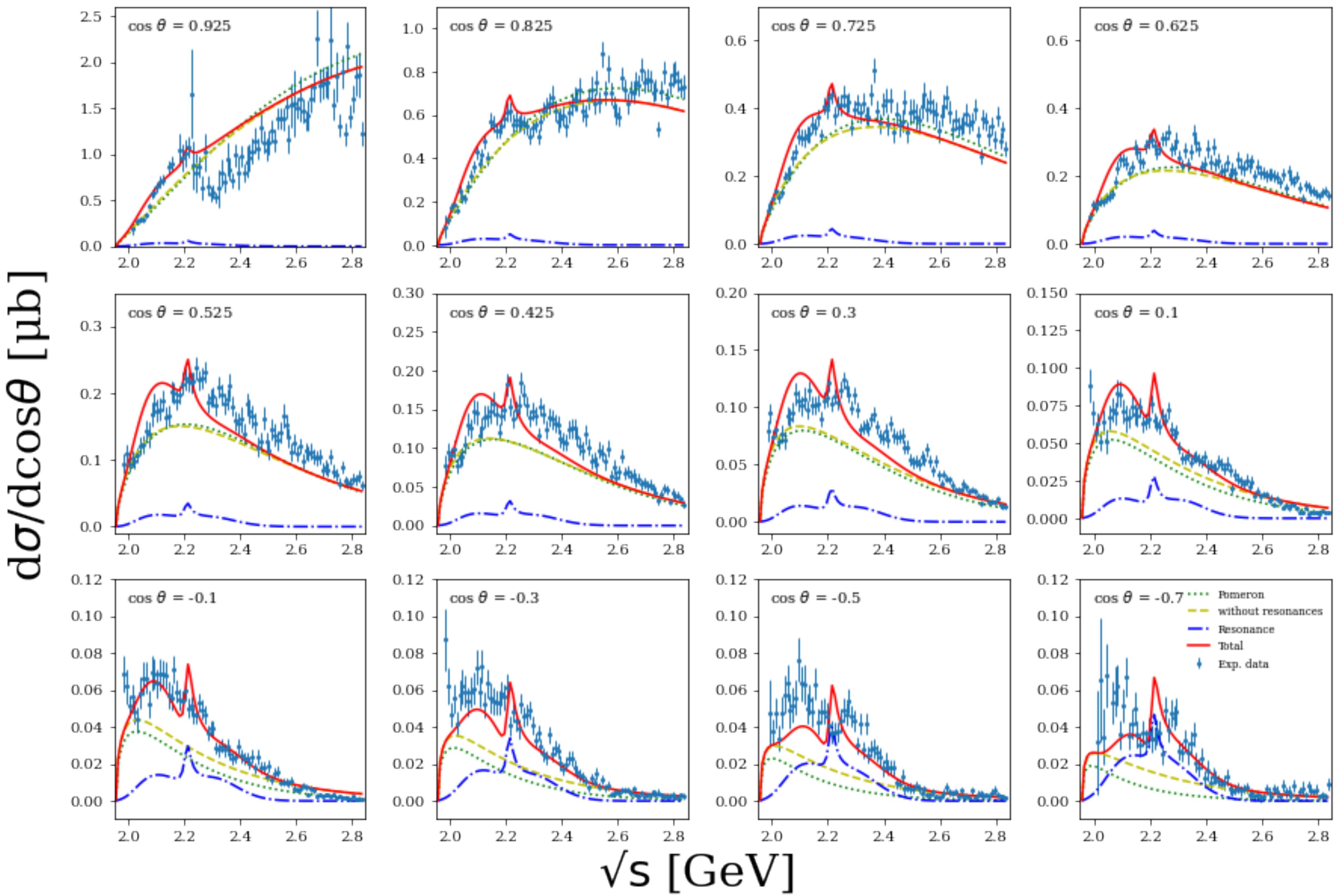
- **The Pomeron and resonances seems to important**

Differential cross section (1)

compared with the CLAS data

PRC 89, 055208; 90, 019901(2014)

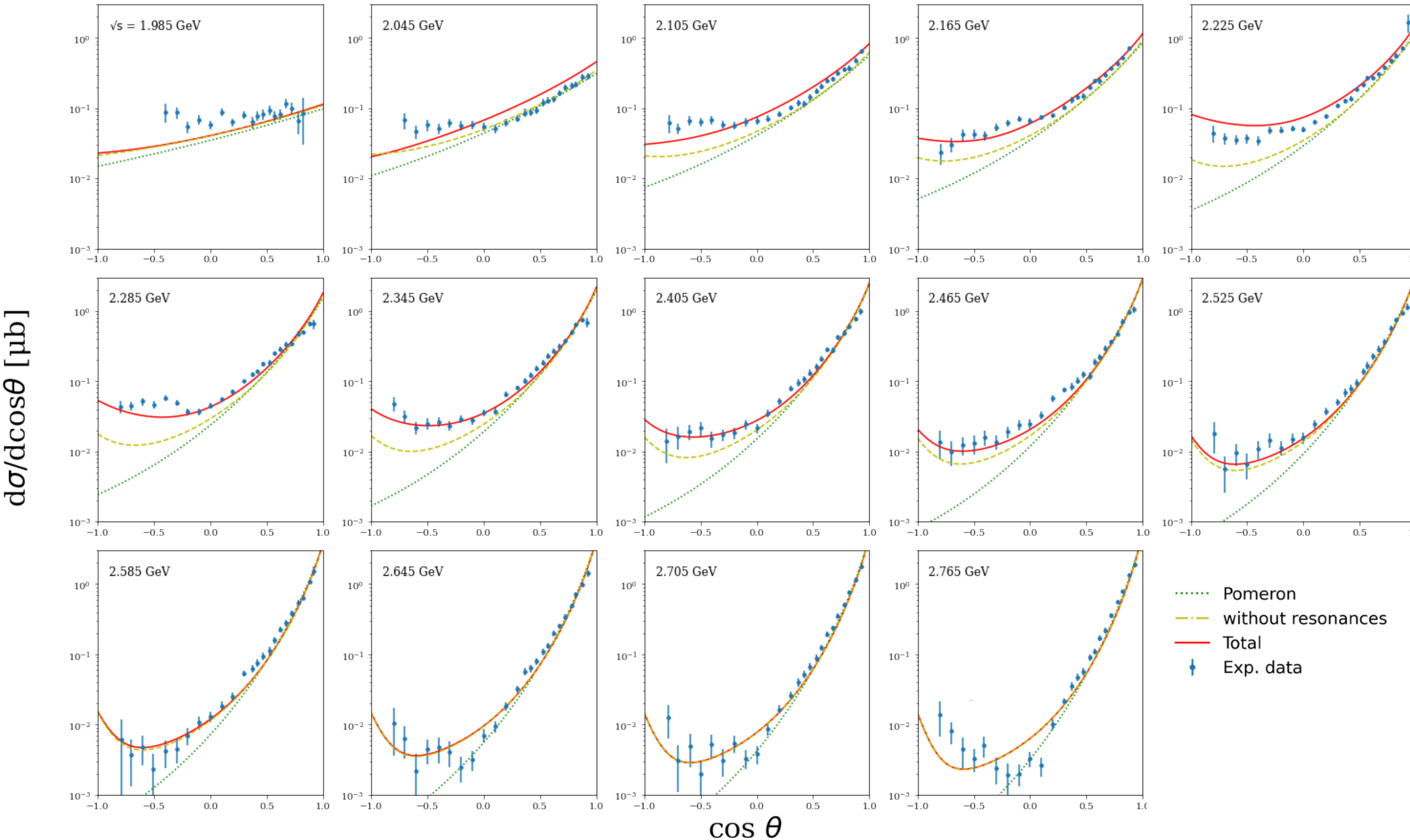
Preliminary



Differential cross section (2)

compared with the CLAS data
PRC 89, 055208; 90, 019901(2014)

Preliminary



Spin density matrix elements (SDMEs)

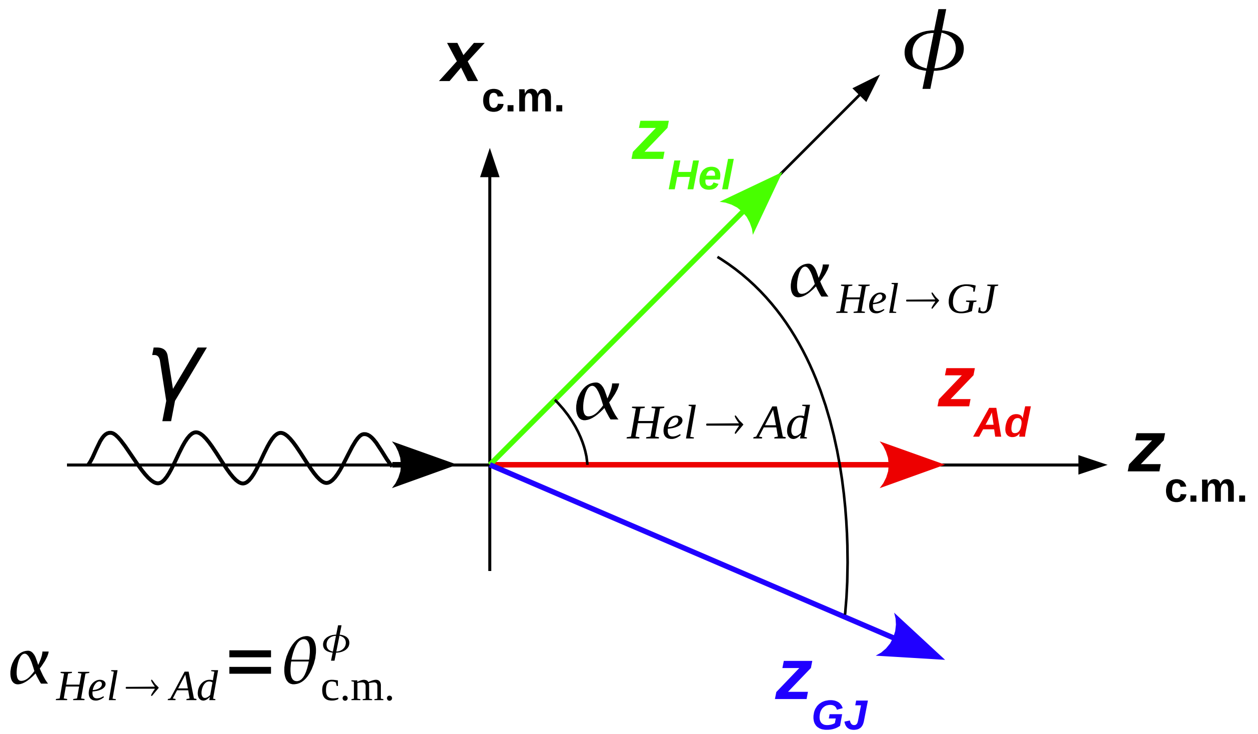
$$\rho^0_{00} \propto \sum_{\lambda^\gamma} |\mathcal{M}_{\lambda^\gamma,\lambda^\phi}|^2_{\lambda^\phi=0}$$

real photon

$$\longrightarrow |\mathcal{M}_{\lambda^\gamma=1,\lambda^\phi=0}|^2 + |\mathcal{M}_{\lambda^\gamma=-1,\lambda^\phi=0}|^2$$

nonzero ρ^0_{00} is an evidence of helicity flip ($\gamma \to \phi$)

ρ^0_{00} is Not Lorentz invariant

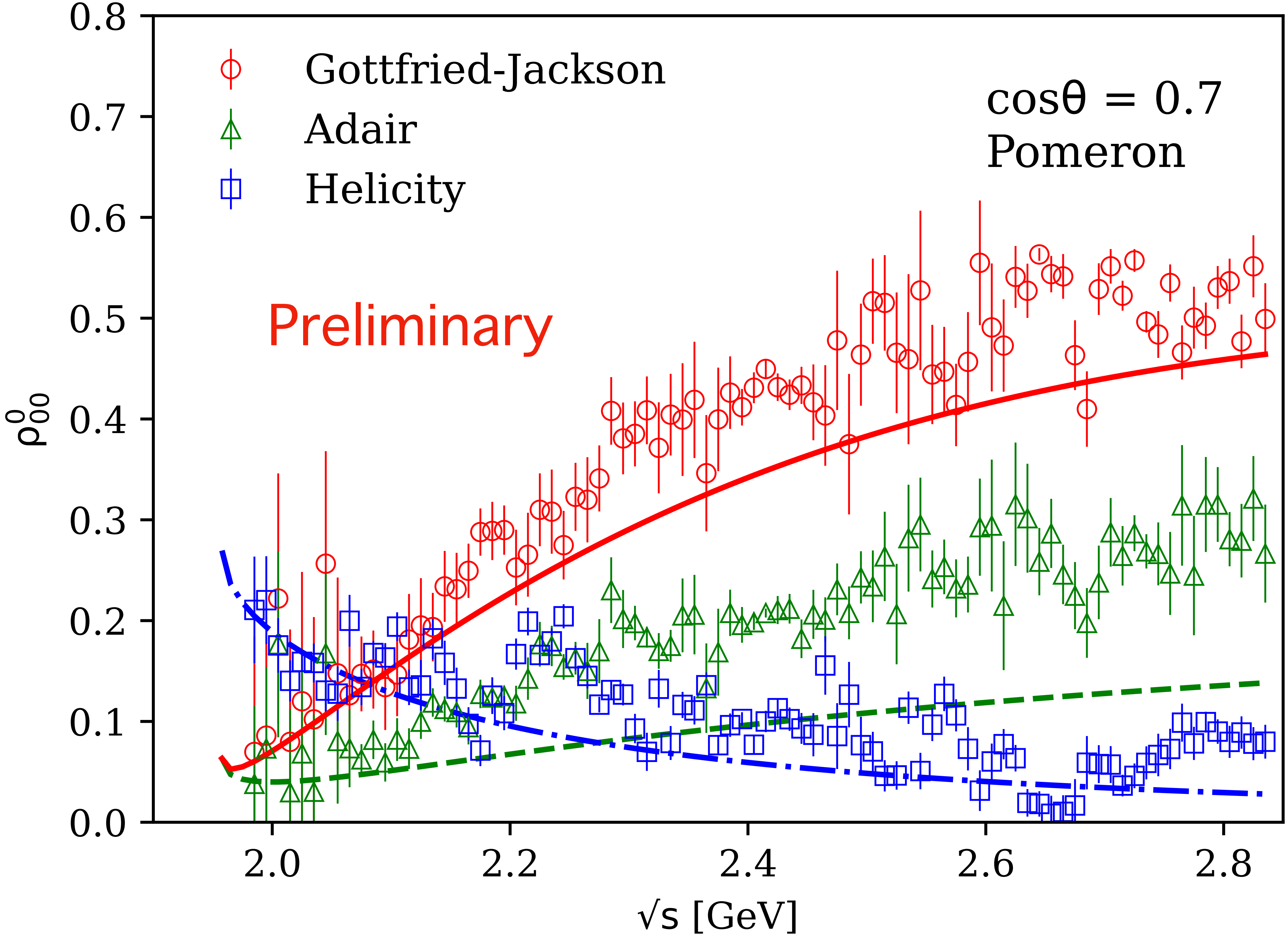


z_{Hel} : direction of ϕ (SCHC)
s-channel helicity conservation

z_{Ad} : coinsides with $z_{\text{c.m.}}$

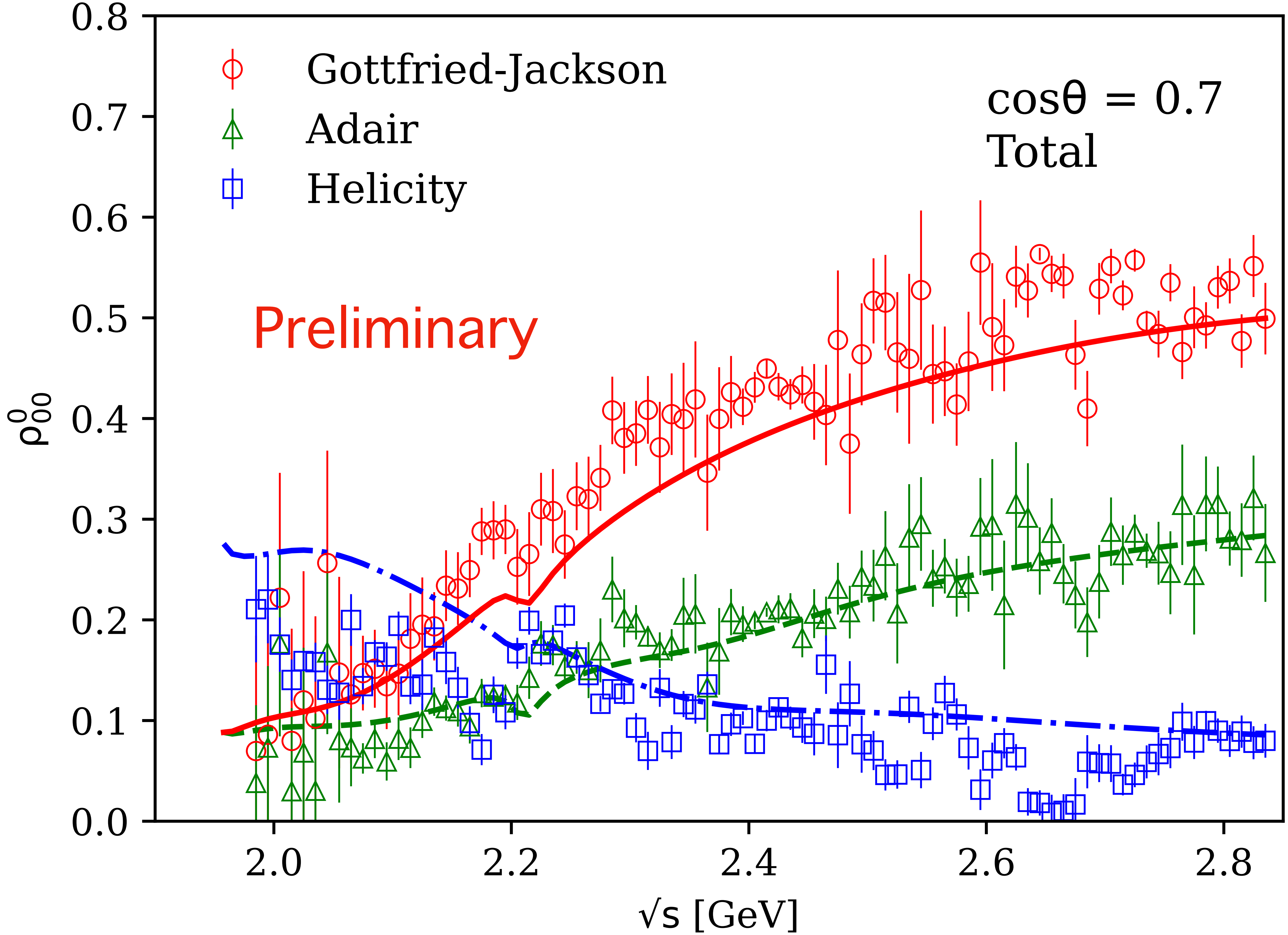
z_{GJ}: direction of γ in ϕ rest frame
t-channel helicity conservation (TCHC)

Spin density matrix elements (SDMEs)



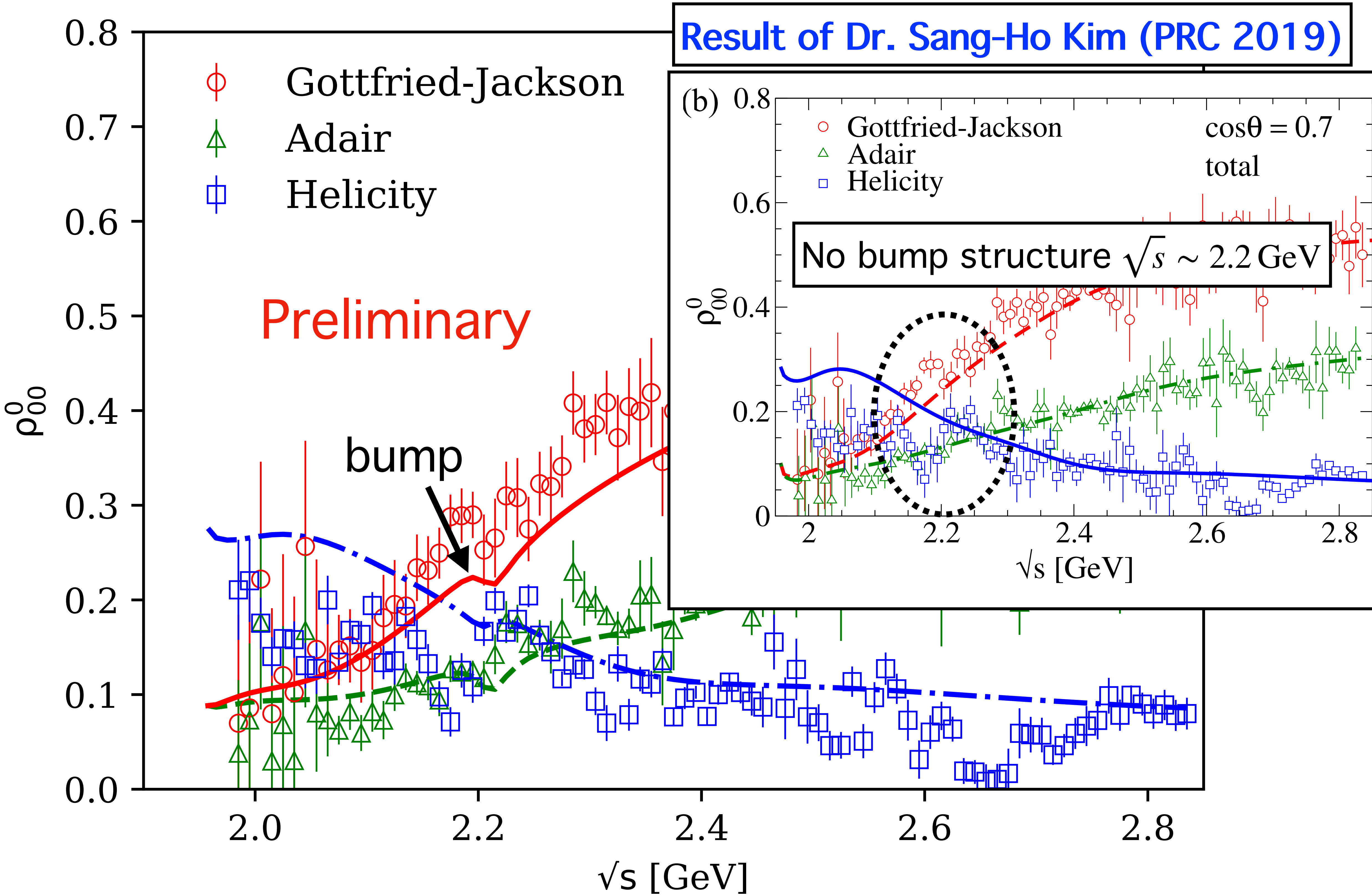
- ρ^0_{00} **is underestimated in all three frames**

Spin density matrix elements (SDMEs)



- **The result show better agreement with data**

Spin density matrix elements (SDMEs)



- The bump can be reproduced by P_s

Summary

- We investigate ϕ-photo- and electroproduction including a pentaquark molecular $K^*\Sigma$ bound-state (P_s) to explain experiments

- We confirmed that some behaviors of SDMEs can be explained by P_s contribution

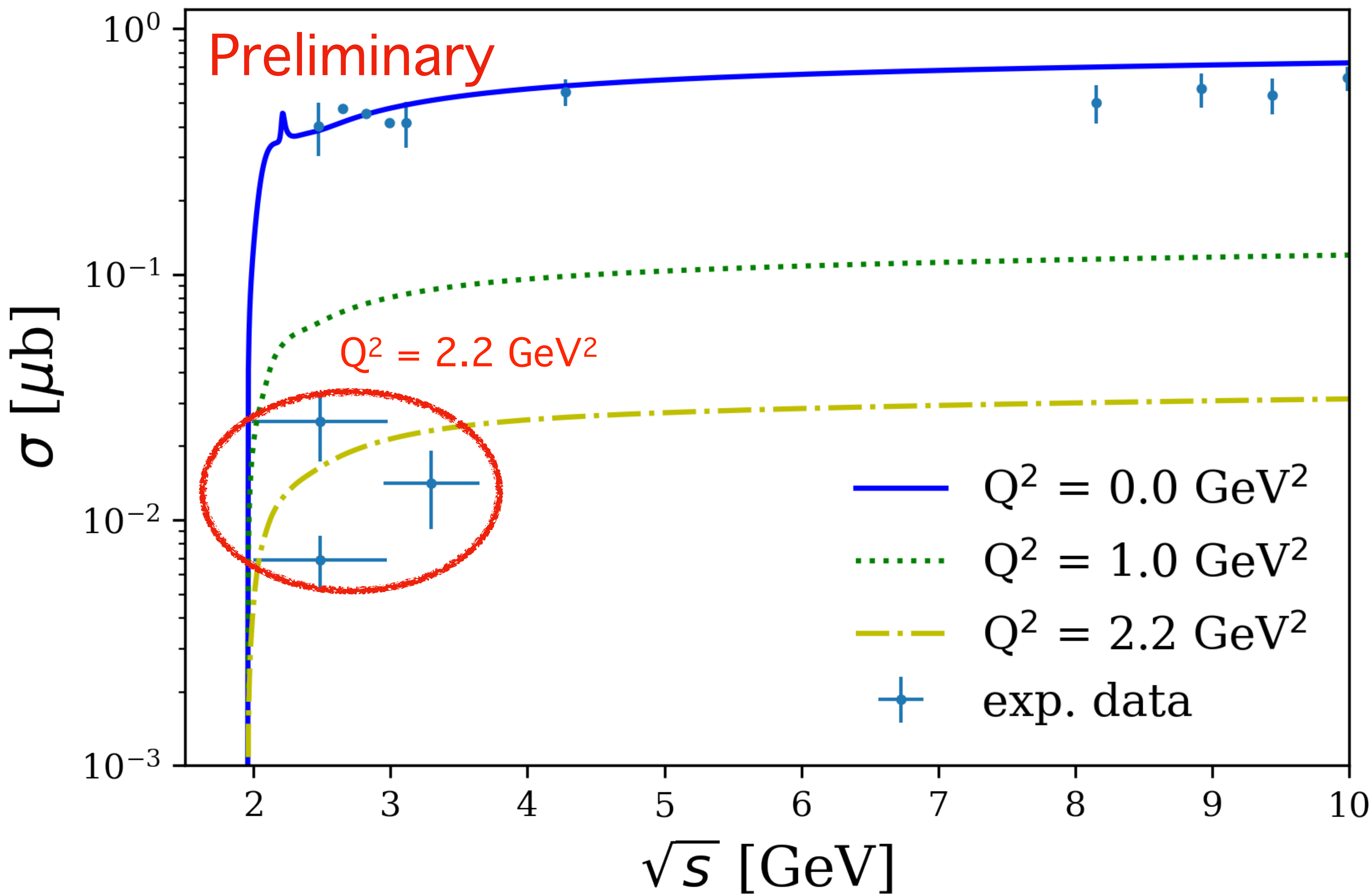
Outlook

- Additional investigates for better understanding of P_s are in the process and will be appear soon

Outlook

Electroproduction ($Q^2 > 0$, virtual photon)

J. Ballam et al. PRD 7, 3150 (1973)
D. P. Barber et al., Z. Phys. C 12, 1 (1982)
R. M. Egloff et al., PRL **43**, 657(1979)
D.G. Cassel et al., PRD 24, 2787 (1981)
J. P. Santoro et al.(CLAS), PRC 78, 025210 (2008)



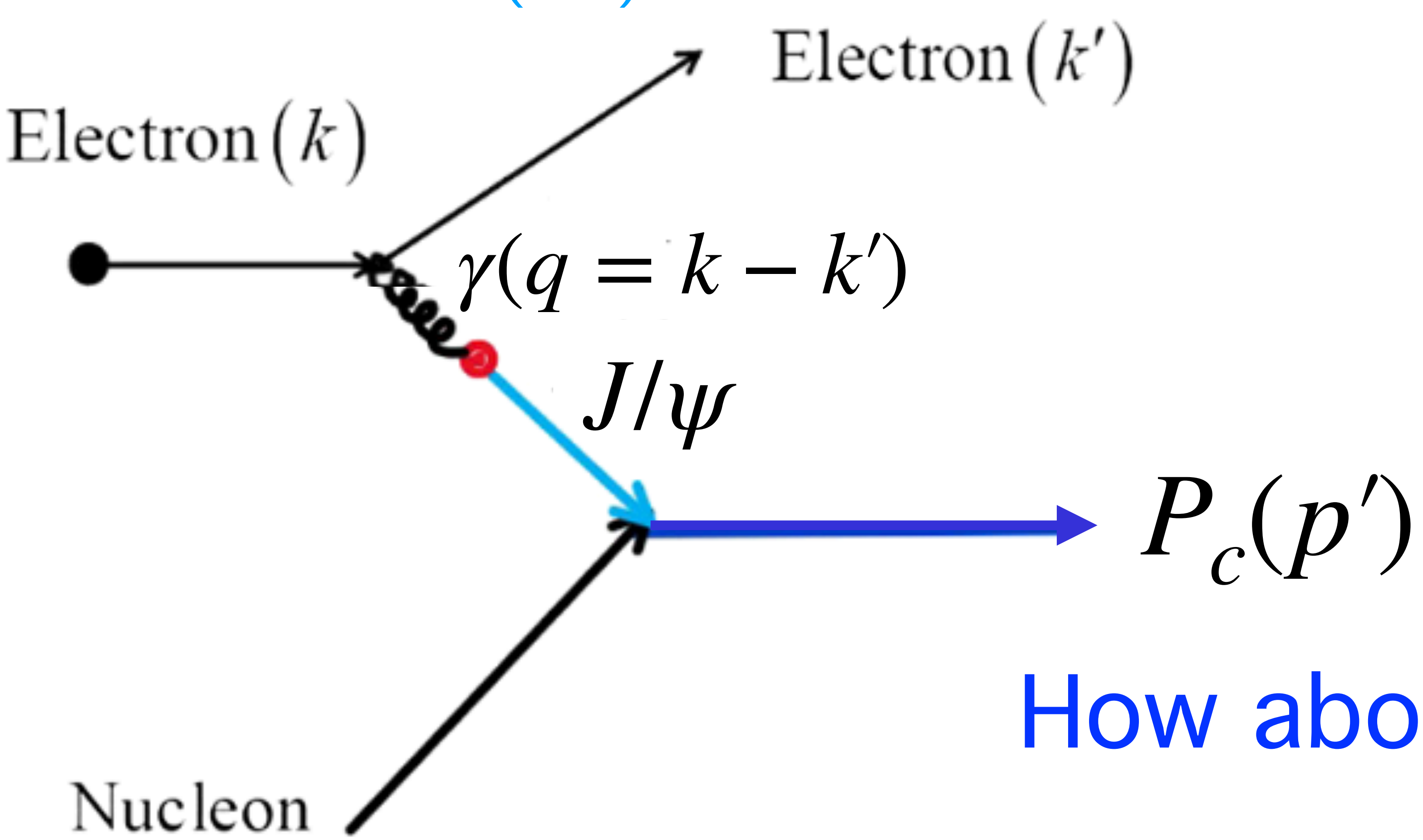
Outlook

PHYSICAL REVIEW D **105**, 114023 (2022)

Production of $P_c(4312)$ state in electron-proton collisions

In Woo Park,[1] Sungtae Cho,[2,3] Yongsun Kim,[4,3,*] and Su Houng Lee[1,†]

Electron-Ion Collider (EIC)



How about P_s?

Thank you for your attention!

Backup

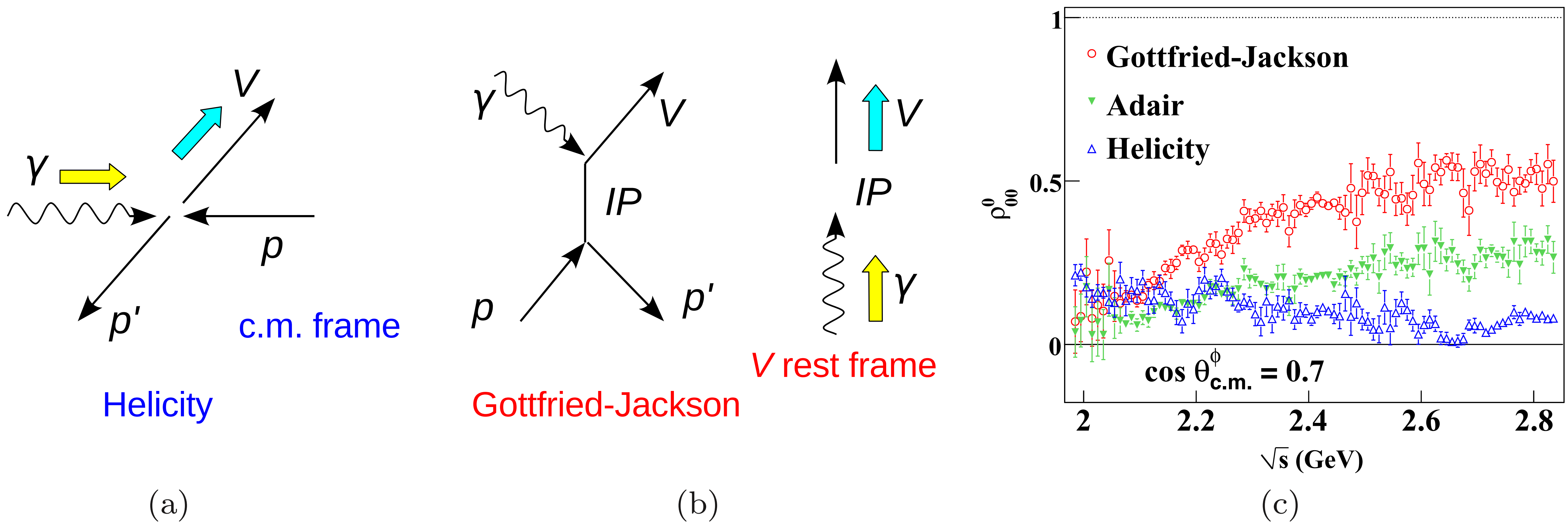


FIG. 36. (Color online) Helicity conservation in the process $\gamma p \to V p'$, where $V \in \{\rho, \omega, \phi, J/\psi, \ldots\}$ is a generic vector meson: (a) s-channel (SCHC in Helicity frame) (b) t-channel (TCHC in the Gottfried-Jackson frame). If the IP couples like a 0^+ object in (b), one would expect TCHC to hold. The $V = \phi$ data in (c) exhibits strong deviation from TCHC since $\rho^0_{00} \neq 0$, implying non-zero helicity flips. The filled arrows in (a) and (b) depict the spins of the incoming and outgoing vector particles.