Korean EIC & J/ψ Photoproduction

Yongseok Oh
(Kyungpook National University)

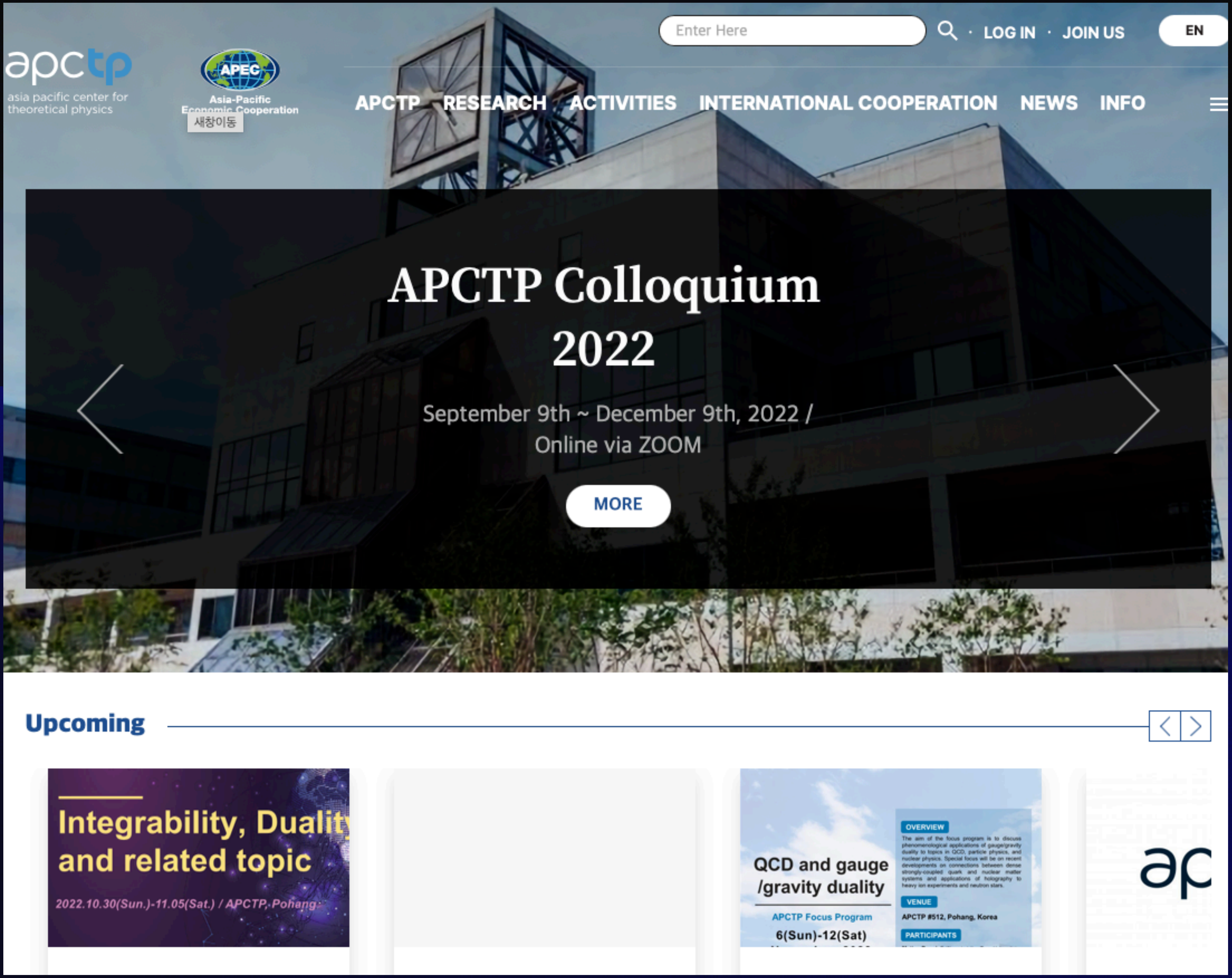
NCU Workshop on EIC Physics and Detectors, National Central University, Dec. 9 - 10, 2022

- Asia Pacific Center for Theoretical Physics (APCTP) & Activities of Korean EIC Community

- J/ψ Photoproduction off Nucleons

Asia Pacific Center for Theoretical Physics (APCTP)

- A hub for our activities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APCTP #512, Pohang, Korea
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17 Member countries
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RCNP (Research Center for Nuclear Physics)
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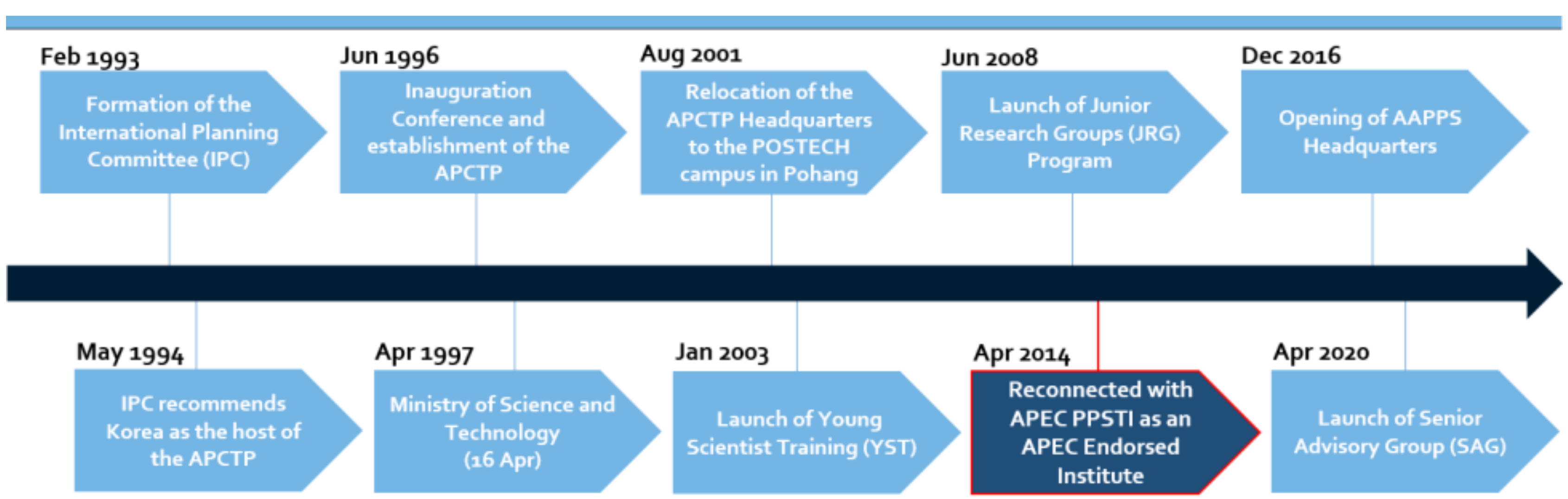
APCTP Milestones

- A hub-institute of theoretical physics in Asia Pacific region
  to facilitate collaboration & exchange of scientists
  to provide a platform for scientists of less advanced region

- Currently, 17 member economies (entities) in the Asia Pacific regions & 34 partner institutes (including IUPAP, AAPPS, KPS, ICTP, ECT*, IOP-CAS, ISSP, IBS, etc.)

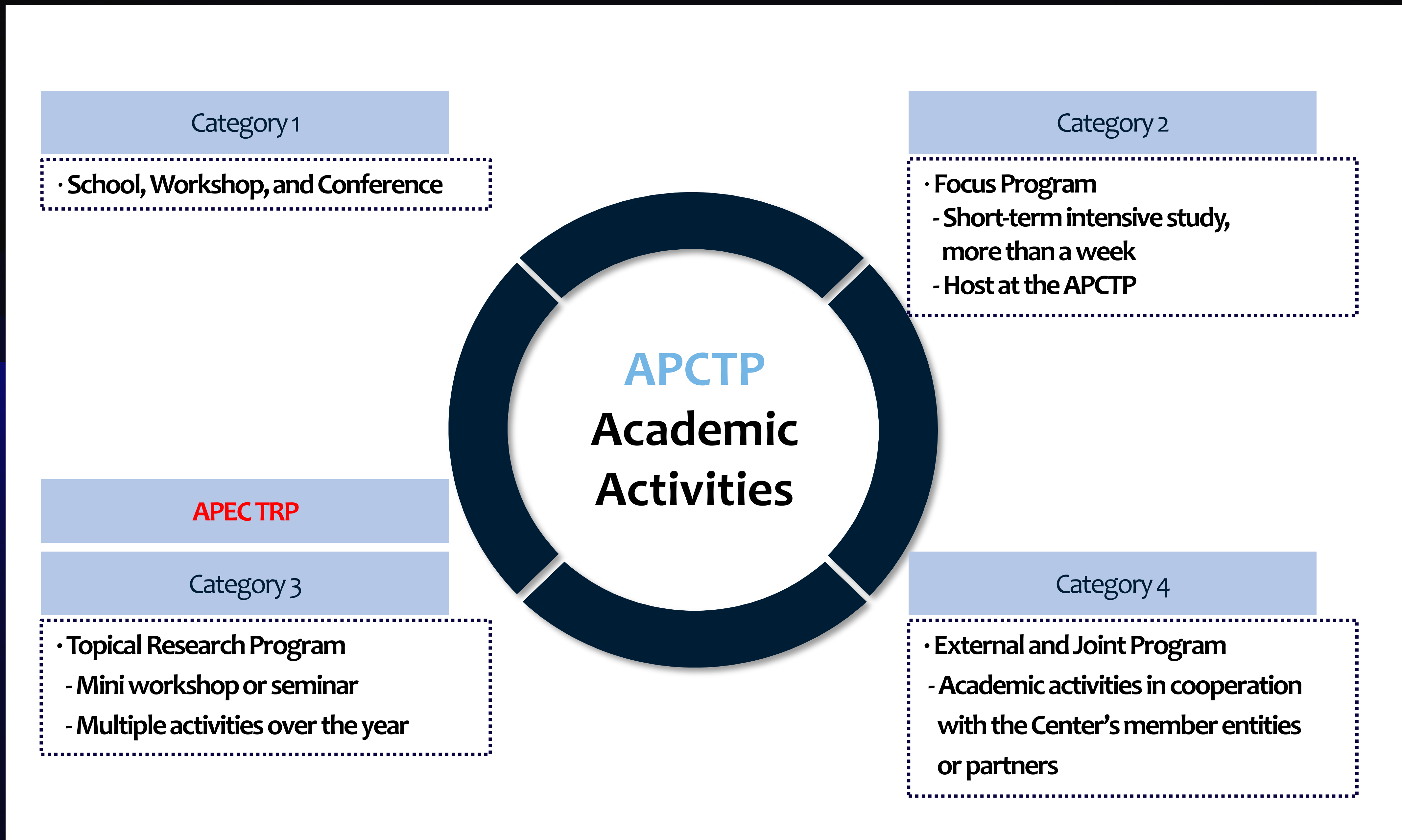
- APCTP headquarters located in Pohang (POSTECH), Republic of Korea



APCTP Activities

- Academic Activity Hub
  - ✓ Int'l/Domestic Conference/Workshop/etc.
  - ✓ Topical Research Program (TRP) **APEC TRP**
  - ✓ Benjamin Lee Professorship
- In-house Research
  - ✓ Junior Research Group (JRG)
  - ✓ Young Scientist Training Program (YST) **APEC YST**
  - ✓ Senior Advisory Group (SAG)
- International Cooperation
  - ✓ Cooperation with APEC, AAPPS
  - ✓ Publication of the AAPPS Bulletin

Academic Activities



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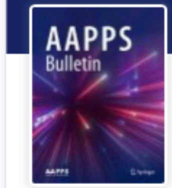

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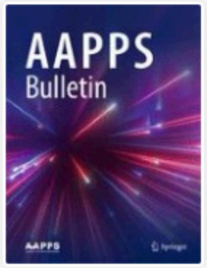

Volume 32, issue 1, December 2022

34 articles in this issue

[Advances of LINAC-based boron neutron capture therapy in Korea](#)
Young-soon Bae, Dong-Su Kim ... Sun-Sun Park
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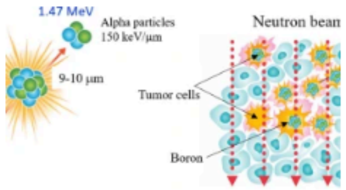

[Manipulation and enhancement of asymmetric steering via down-converted nondegenerate photons](#)
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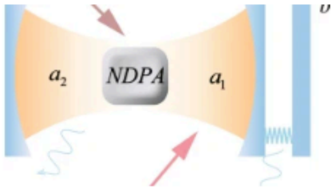


Nuclear Physics
LIU, Weiping, China Institute of Atomic Energy, Beijing
MA, Yong Liang, Hangzhou Institute for Advanced Study, UCAS, Hangzhou
OH, Yongseok, Kyungpook National University, Daegu
SHIMOURA, Susumu, University of Tokyo, Tokyo
YAN, Hai-Yang, Institute of Nuclear Physics and Chemistry, Mianyang

Workshops

Workshop on Nucleon and Resonance Structure with Hard Exclusive Processes,
IPN Orsay, France, May 29-31, 2017

Exploring Hadrons with Electromagnetic Probes: Structure, Excitations, Interactions,
JLAB, Nov. 2-3, 2017

The Nature of Hadron Mass and Quark-Gluon Confinement from JLAB Experiments
in the 12-GeV Era, APCTP, Pohang, July 1-4, 2018

2nd PSQ@EIC Meeting (APCTP-CFNS Joint Meeting),
Kyongju+online, July 19-23, 2021

APCTP Focus Program in Nuclear Physics 2021,
Kyongju+online, Jul. 19-24, 2021

Light Cone 2021: Physics of Hadrons on the Light Front, Jeju Island,
Nov. 29-Dec. 4, 2021

Workshops

APCTP Workshop on Nuclear Physics 2022, Physics of Excited Hadrons in the Present and Future Facilities, Jeju Island, July 11-16, 2022

APCTP Focus Program in Nuclear Physics 2022, Hadron Physics Opportunities with JLab Energy and Luminosity Upgrade, APCTP, Pohang, July 18-23, 2022

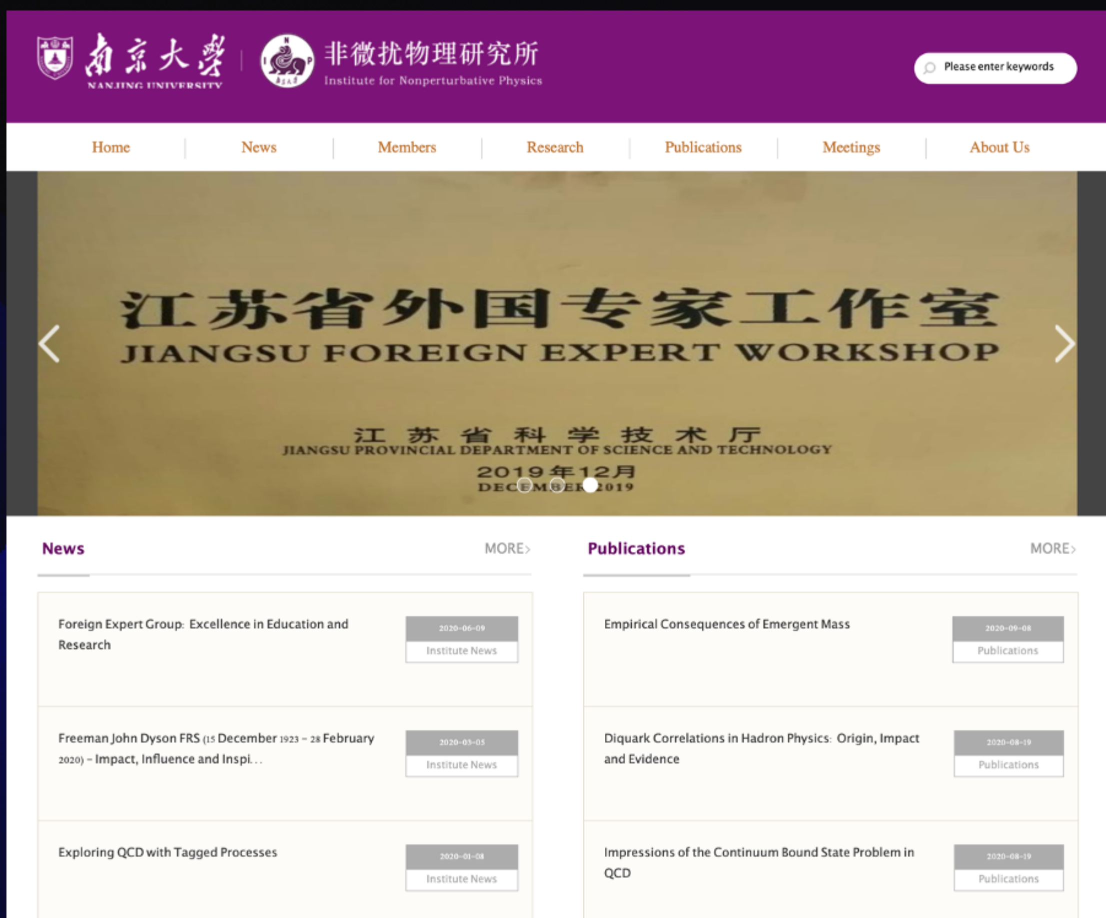
APCTP Workshop on the Physics of Electron Ion Collider, Howard Johnson Hotel, Incheon, Nov. 2-4, 2022

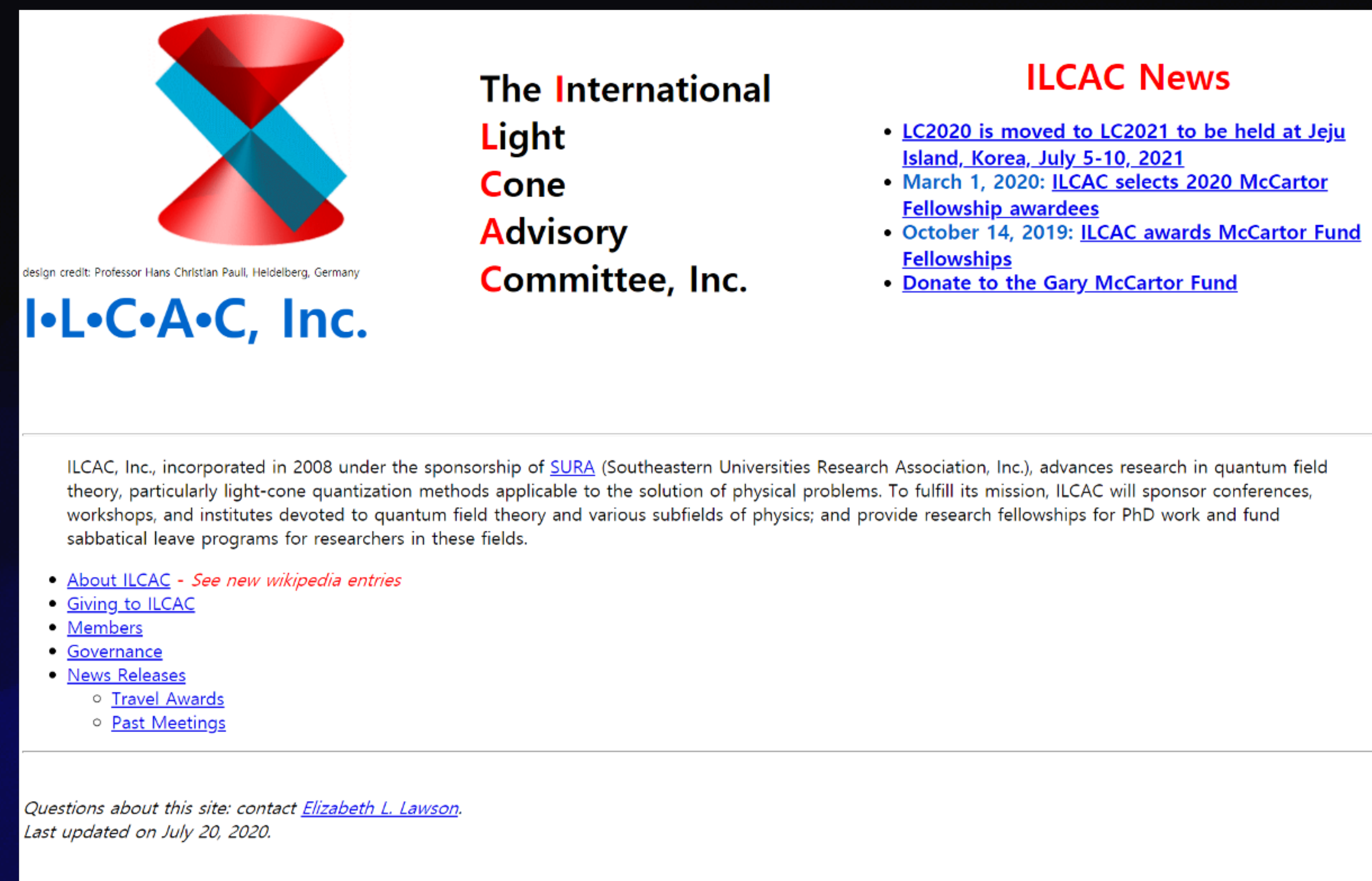
APCTP-ECT* Joint Workshop: Exploring resonance structure with transition GPDs, ECT*, Trento, Italy, May 2023

APCTP Focus Program in Nuclear Physics 2023: Hadron Physics with Hadronic Probes, APCTP, Pohang, Korea, July 2023

Baryons 2025 (17th International Conference on the Structure of Baryons), Jeju Island, Summer 2025

Partnership





Joint workshop with Bogolyubov Laboratory of Theoretical Physics of Joint Institute for Nuclear Physics, Dubna, Russia since 2007.

From Yongsun Kim’s slides

Nuclear/Particle Experiment Groups in Korea

CNU	Chonnam Nat. Univ.
KNU	Kyungpook Nat. Univ.
KU	Korea Univ.
IBS	Institute of Basic Science
Inha	Inha Univ.
JBNU	Jeonbuk Nat. Univ.
PNU	Pusan Nat. Univ.
SJU	Sejong Univ.
SKKU	Sungkyunkwan Univ.
SNU	Seoul Nat. Univ.
UOS	Univ. of Seoul
Yonsei	Yonsei Univ.

~10 institutes

~100 active members

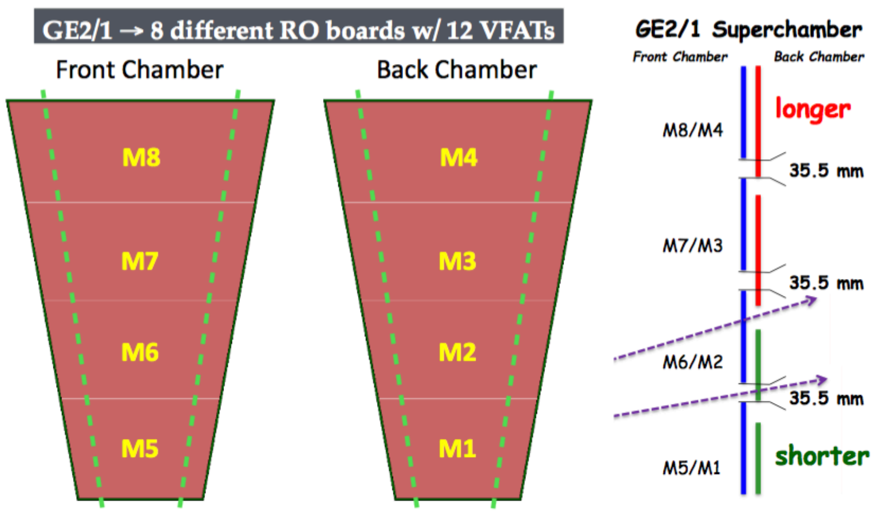
From Yongsun Kim's slides

Precedent Contributions for International Collaborations

KOREA-CERN COLLABORATION PROGRAM (since 2006)
(K-CMS, KO-ALICE, & Theory, now about 4M USD per year)

RPC gap production for CMS

- A longstanding hardware activity from 1990s by Korean high energy & nuclear physics groups

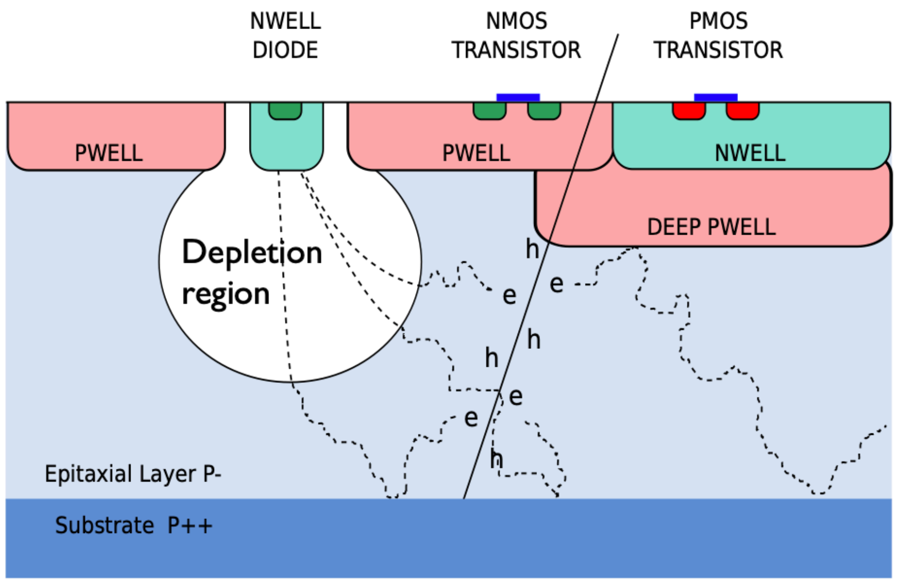


Mass production of GEM foils

- CMS upgrade
- R&D from 2014 by K-CMS group
- GE1/1, ME0

MAPS upgrade for ALICE ITS

- R&D for Pixel chip design and beam test
- Ko-ALICE groups
  - Inha U., Yonsei U., PNU



From Yongsun Kim's slides

Potential Korean involvement for EIC

From Yongsun Kim's slides

To Maximize Productivity …

Extension of ongoing hardware developments for EIC detectors

- ALICE ALPIDE, Focal -> EIC vertex tracker and calorimeter
- CMS MTD, GEM -> EIC LGAD, μRWELL
- FCC DRC -> EIC calorimeter (upgrade)

Active collaboration with foreign groups

- BNL, ORNL, LANL, RIKEN, and more…
- Allows concentrating on well defined tasks and minimizes risks

From Yongsun Kim's slides

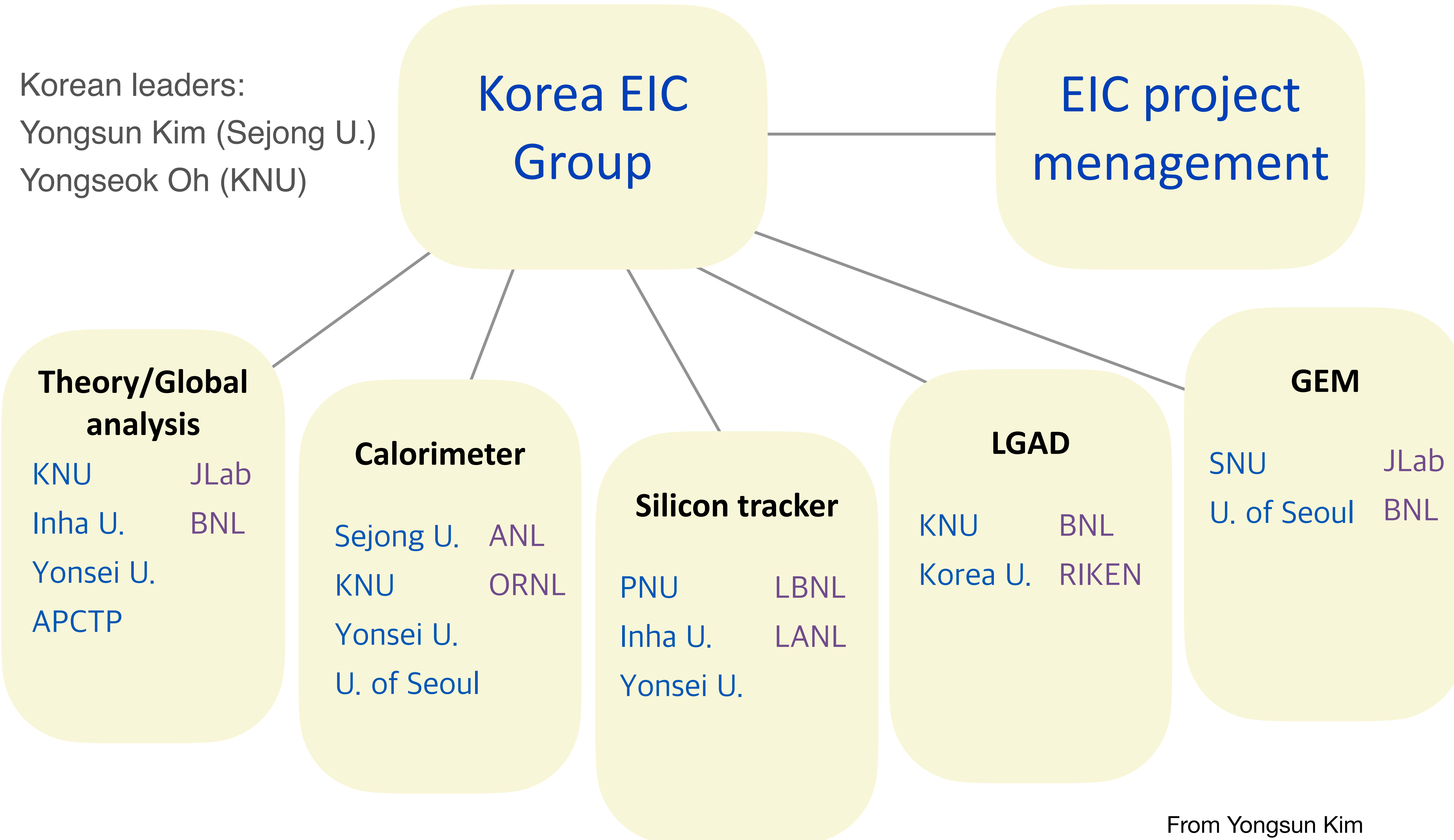
- **Korean groups are very interested in the involvement of EIC program**
  - Active discussion ongoing among nuclear, high energy, hadron physics societies
- **For EPIC, we are interested in contribution of following projects**
  - Electronics for calorimeters (HGCROC)
  - μRWELL gas detector
  - Silicon pixel tracker
  - LGAD sensor
  - Dual readout calorimeter
- **To realize the involvement, we are …**
  - constructing the concrete goal and plan to be achieve with limited manpower and funding
  - open for international collaboration particularly with labs in the US and nearby countries
  - seeking for substantial long-term support for R&D and detector construction

From Yongsun Kim's slides

Proposed partnership w/ international collab.

Expected manpower: ~10 universities, ~ 50 members (including ~15 faculty members)

Korean leaders:
Yongsun Kim (Sejong U.)
Yongseok Oh (KNU)



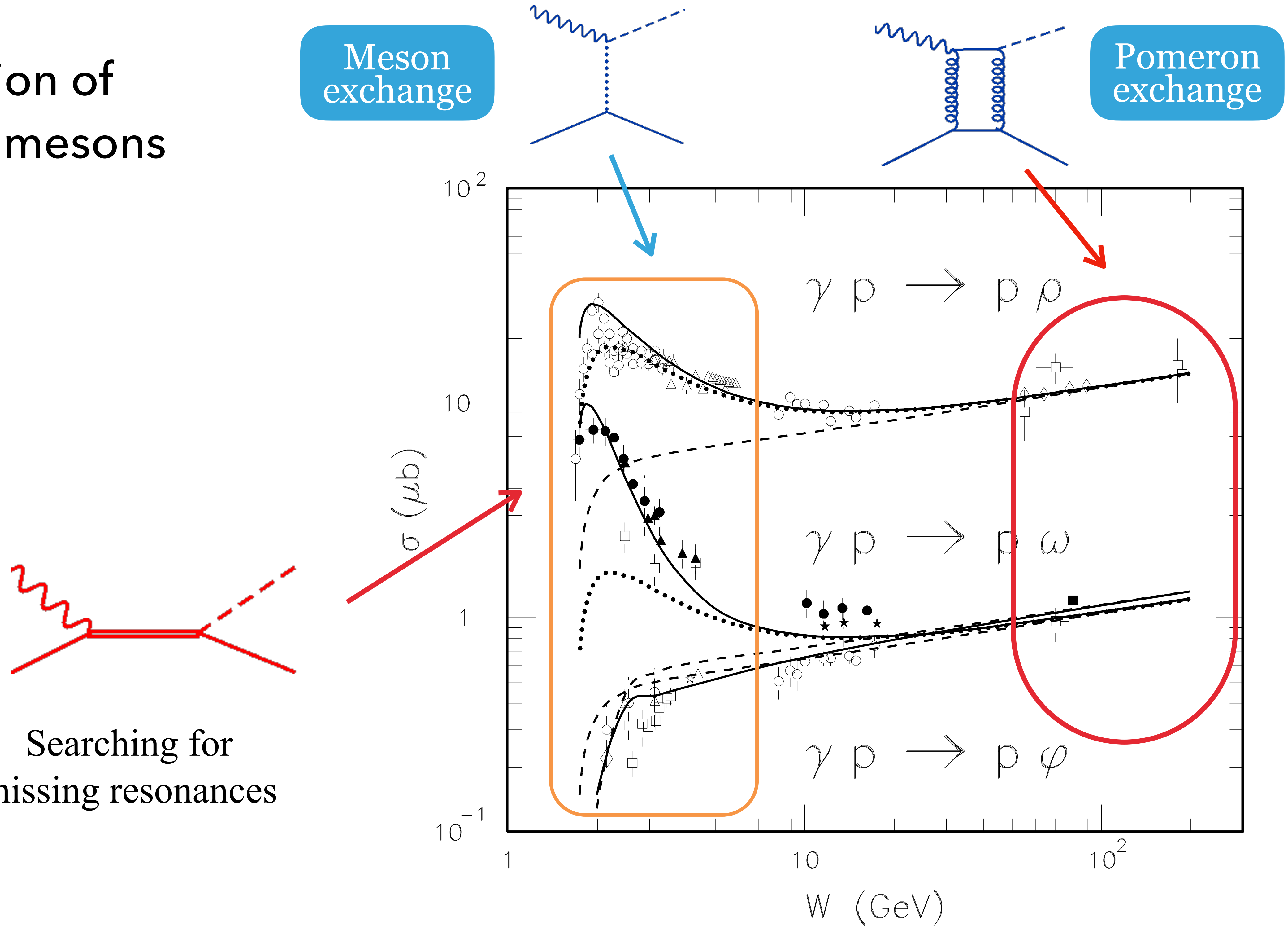
From Yongsun Kim

J/ψ Photoproduction off Nucleons

T.-S. H. Lee, S. Sakinah, Y. Oh, arXiv:2210.02154, to be published in Eur. Phys. J. A

Models for VM photoproduction

Photoproduction of neutral vector mesons



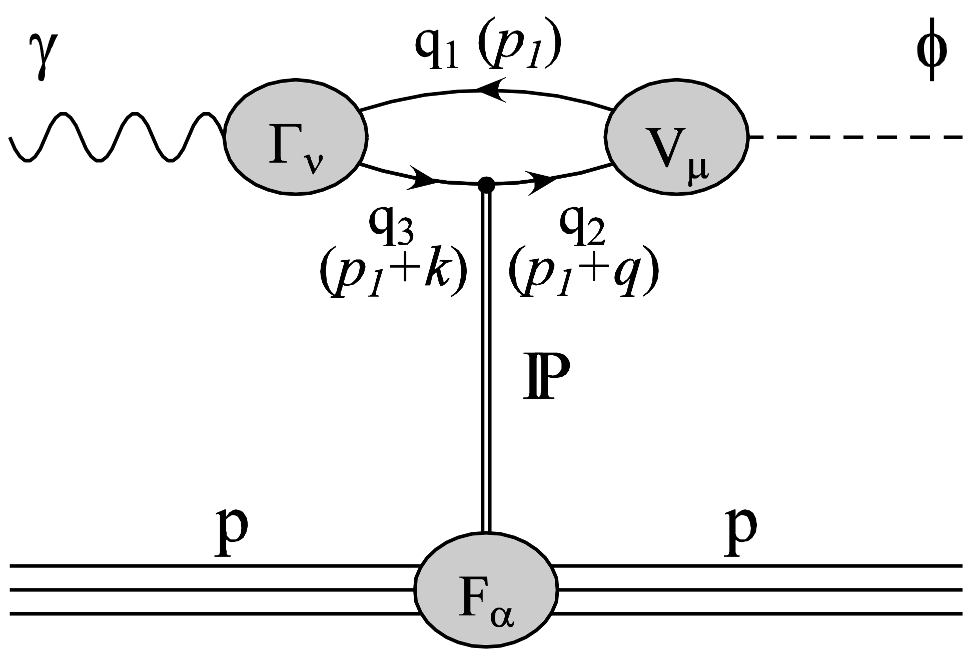
J.M. Laget, PLB 489 (2000)

$\gamma N \to VN(V = \omega, \rho, \phi, K^*)$

Light VM photoproduction

PRODUCTION MECHANISMS

Pomeron Exchange Model



Donnachie-Landshoff

Pomeron: C=+1 isoscalar photon

$$\mathcal{M} = \varepsilon_\nu(\gamma)\mathcal{M}^{\mu\nu}\varepsilon^*_\mu(V)$$

$$\mathcal{M}^{\mu\nu} = i12e\frac{M_V^2\beta_q\beta_{q'}}{f_V}\frac{1}{M_V^2-t}\left(\frac{2\mu_0^2}{2\mu_0^2+M_V^2-t}\right)F_1(t)\bar{u}(p')\left\{k\cdot\gamma g^{\mu\nu}-k^\mu\gamma^\nu\right\}u(p)G_P(t)$$

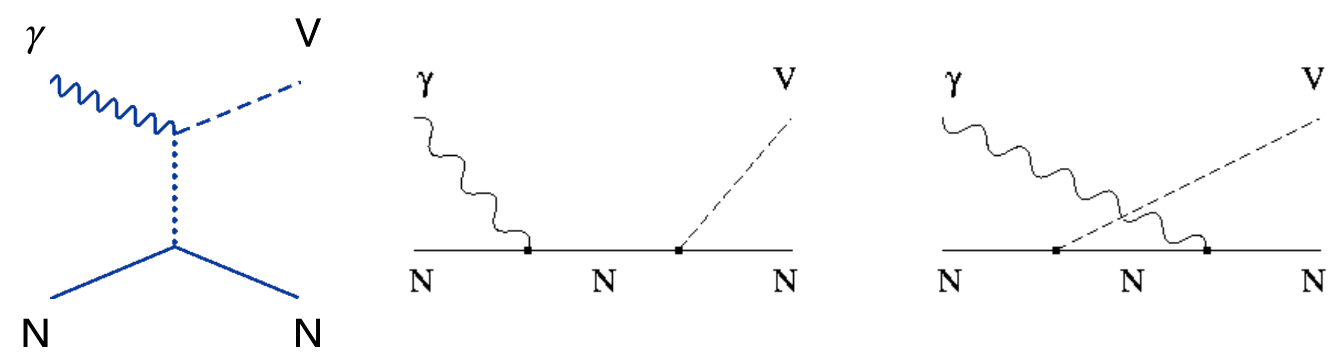
$$G_P(t) = \left(\frac{s}{s_0}\right)^{\alpha(t)-1}\exp\left\{-i\frac{\pi}{2}\left[\alpha(t)-1\right]\right\}, \qquad \alpha(t) = 1.08 + 0.25t$$

$\gamma N \to VN(V = \omega, \rho, \phi, K^*)$

Light VM photoproduction

PRODUCTION MECHANISMS

Meson exchange and nucleon pole terms



$$\mathcal{L} = \frac{e g_{V\gamma\varphi}}{M_V}\varepsilon^{\mu\nu\alpha\beta}\partial_\mu V_\nu \partial_\alpha A_\beta \varphi + \frac{g_{\varphi NN}}{2M_N}\bar{N}\gamma^\mu\gamma_5\partial_\mu\varphi N$$
$$- e\bar{N}\left(A_\mu\gamma^\mu - \frac{\kappa_p}{2M_N}\sigma_{\mu\nu}\partial^\nu A^\mu\right)N + \mathcal{L}_{VNN}$$

Couplings from

and pion photoproduction studies, etc

$g^2_{\pi NN}/4\pi = 14$, $g^2_{\eta NN}/4\pi = 1$, $g_{\rho NN} = 6.2$, $\kappa_\rho = 1.0$, $g_{\omega NN} = 10.3$, $\kappa_\omega = 0$ $\quad g_{\omega\gamma\pi} = 1.8$, $\quad g_{\omega\gamma\eta} = 0.4$

Motivation for J/ψ production

- Baryon spectrum & structure
  - Recently observed pentaquark state P_c (LHCb Collab.)
  - To understand this state
    - Confirmation by other experiments
    - Understanding of J/ψ-nucleon interactions

$$\gamma + N \rightarrow J/\Psi + N$$

- Test J/ψ-N potential extracted from LQCD
- Predict nuclei with hidden charms
- Investigate gluonic distributions in nuclei

Models of J/ψ photo-production

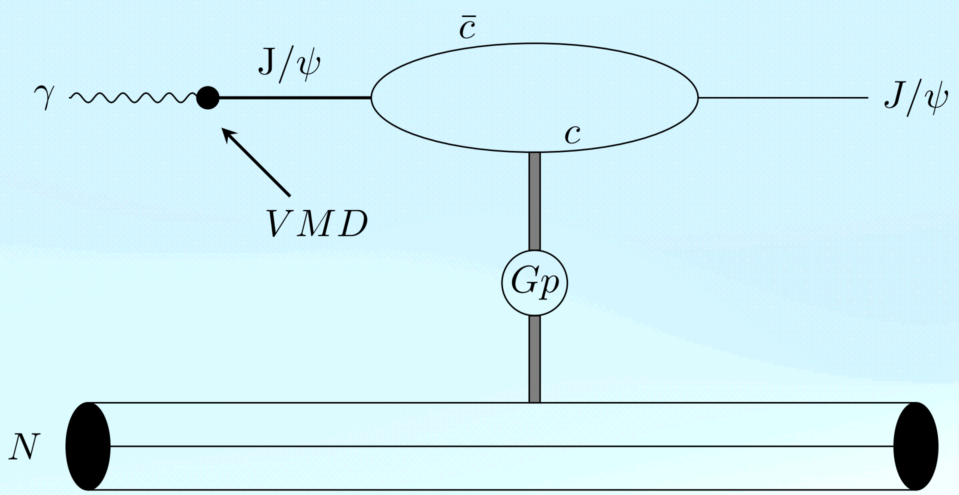
Models in the market

1. Pomeron exchange model (Pom-DL)
2. Pomeron + J/ψ-N potential model (Pom-pot)
3. GPD-based model
4. 2-gluons & 3-gluons exchange model (2g+3g)
5. Holographic approach
6. Pomeron + CQM

With those background, investigate

- N^* (P_c) contributions

Model I



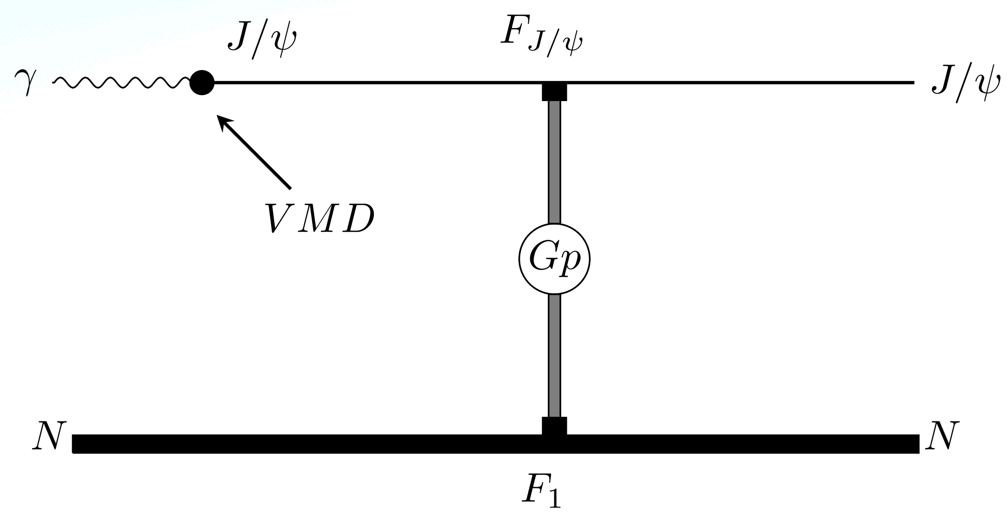


Fig. 2 Pomeron-exchange model of Donnachie and Landshoff (*Pom – DL*). Upper: Pomeron-exchange between quarks in J/Ψ and nucleon, Lower: Pomeron-exchange amplitude Eq. (1) resulted from assuming the Pomeron-photon analogy and using the factorization approximation.

Pomeron-exchange (Pom-DL)

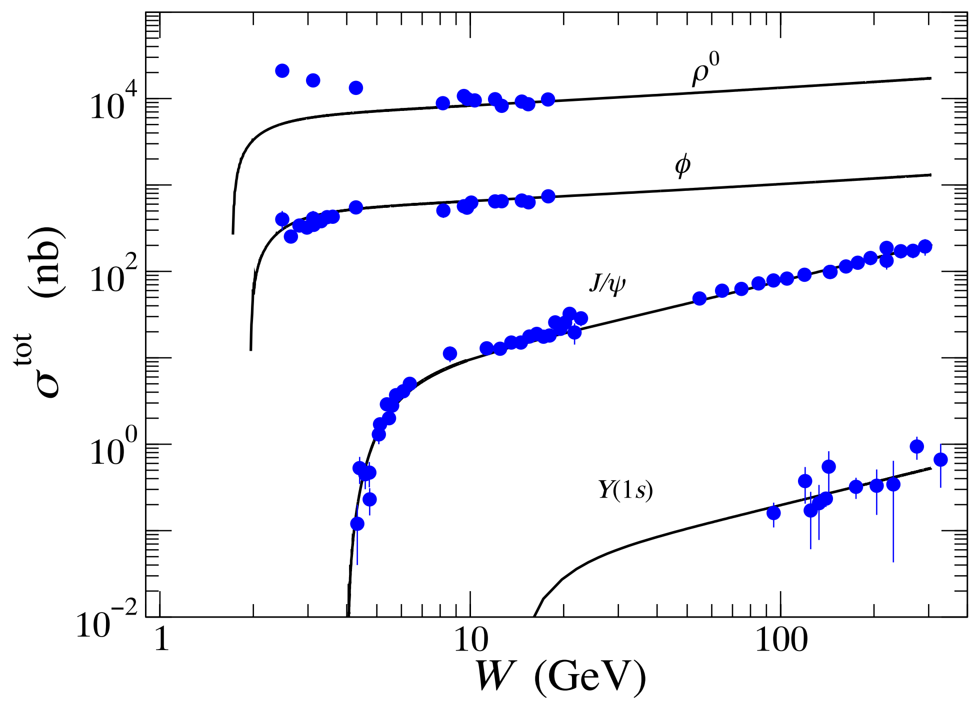


Fig. 9 Fits to the data of the total cross sections (σ^{tot}) of photo-production of ρ^0, ϕ, J/Ψ and $\Upsilon(1s)$ on the proton target. The solid curves are calculated from using the *Pom*-DL model. Data are from Refs. [17, 35–37, 95–106].

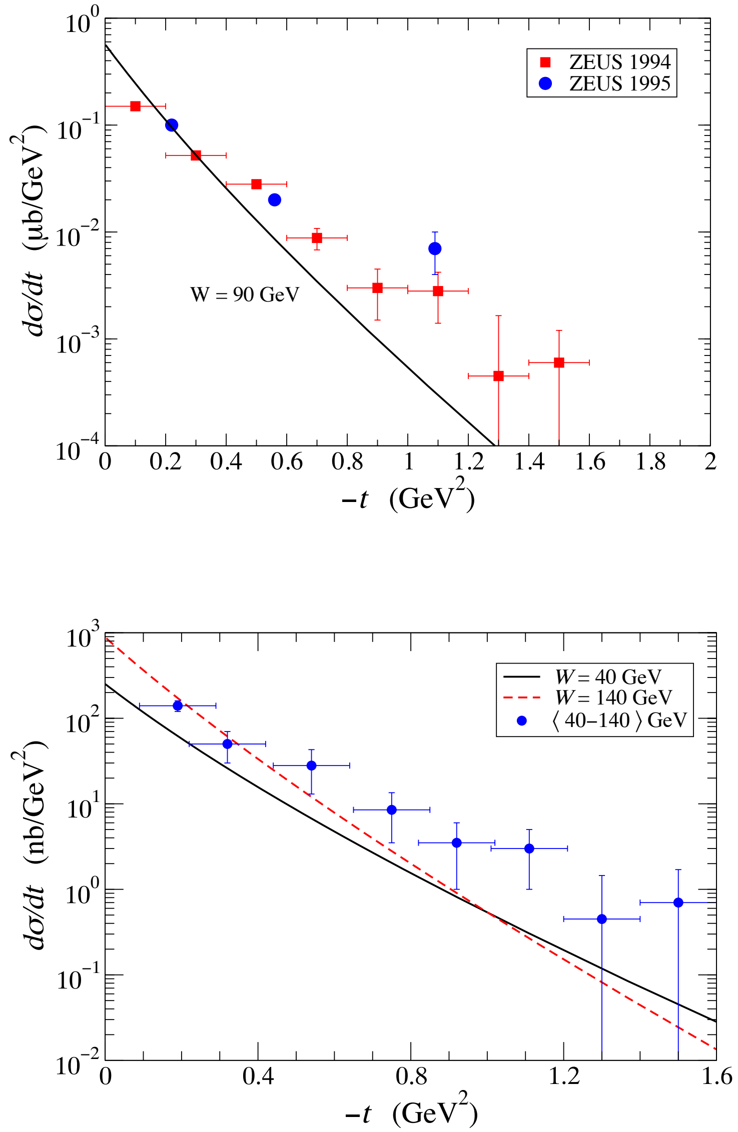


Fig. 10 Differential cross sections from the *Pom*-DL model are compared with ZEUS data [17, 35–37]. Upper: at $W = 90$ GeV; Lower: at $W = 40$ GeV (solid curve) and 140 GeV (dashed curve), data are from averaging the data in the range of $W = 40$-140 GeV .

For light quark VM $\quad \alpha_0 = 1.08 \quad (\text{for } \rho, \omega), \qquad \alpha_0 = 1.12 \quad (\text{for } \phi)$

For heavy quark VM $\quad \alpha_0 = 1.25$

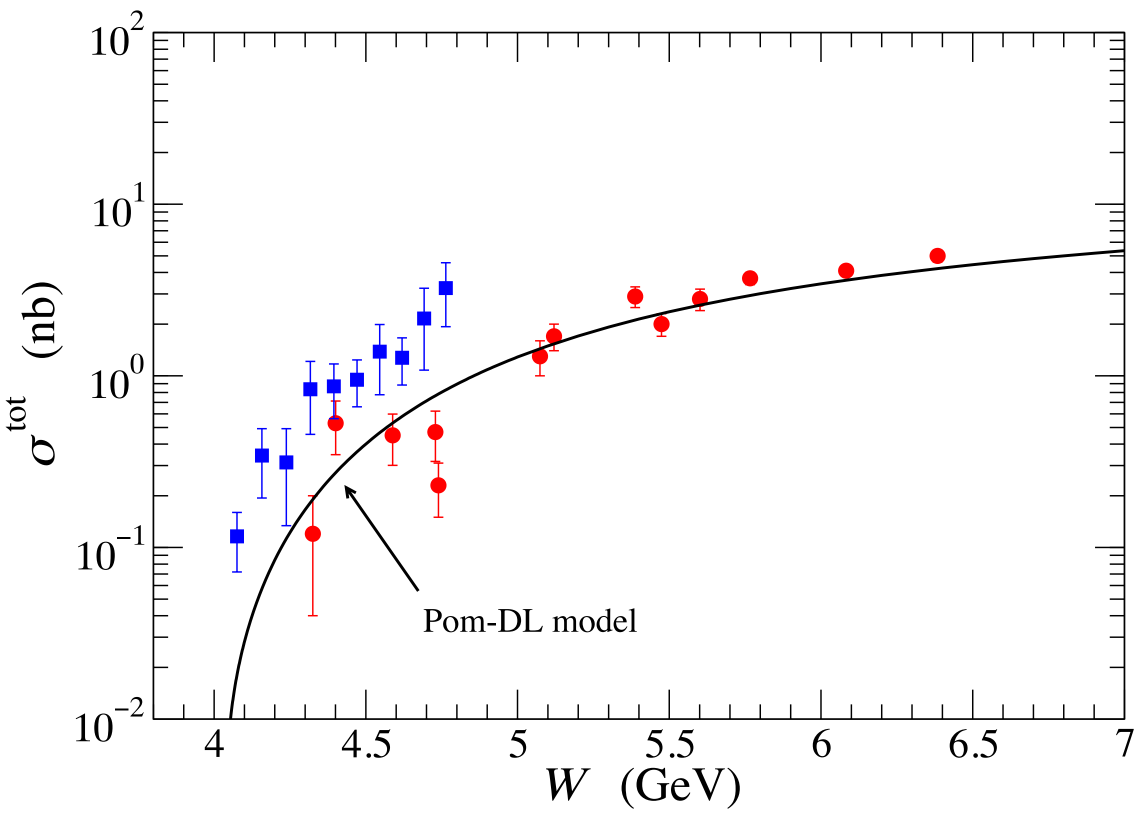


Fig. 12 Total cross sections calculated from the *Pom*-DL model are compared with the data. Solid squares are the JLab data [10].

GlueX, PRL 123 (2019)

Model II

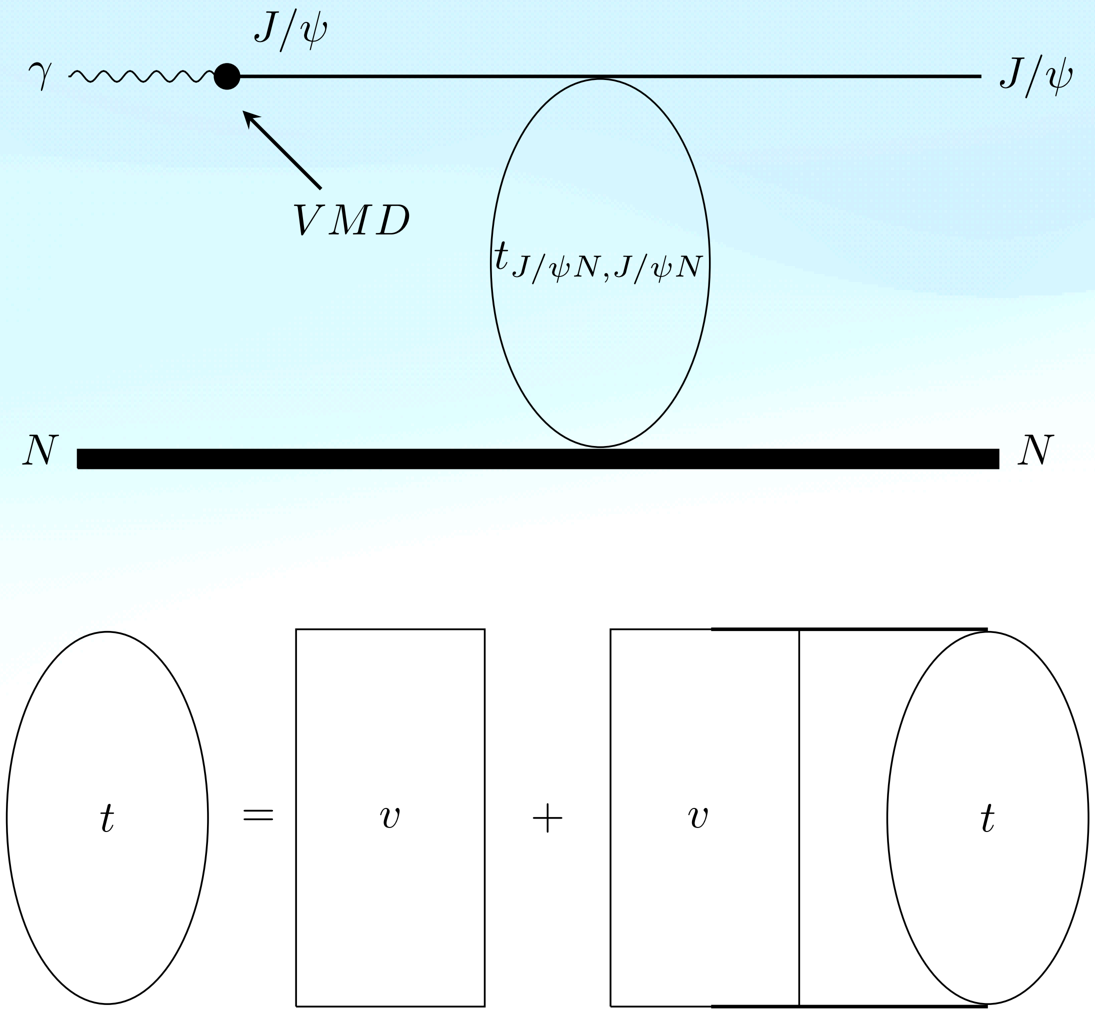


Fig. 3 *Pom*-pot model. Upper: The amplitude of Eq. (2). Lower: J/Ψ-N scattering equation (3). Here, v and t stand for $v_{J/\psi N,J/\Psi N}$ and $t_{J/\psi N,J/\Psi N}$, respectively.

Model III

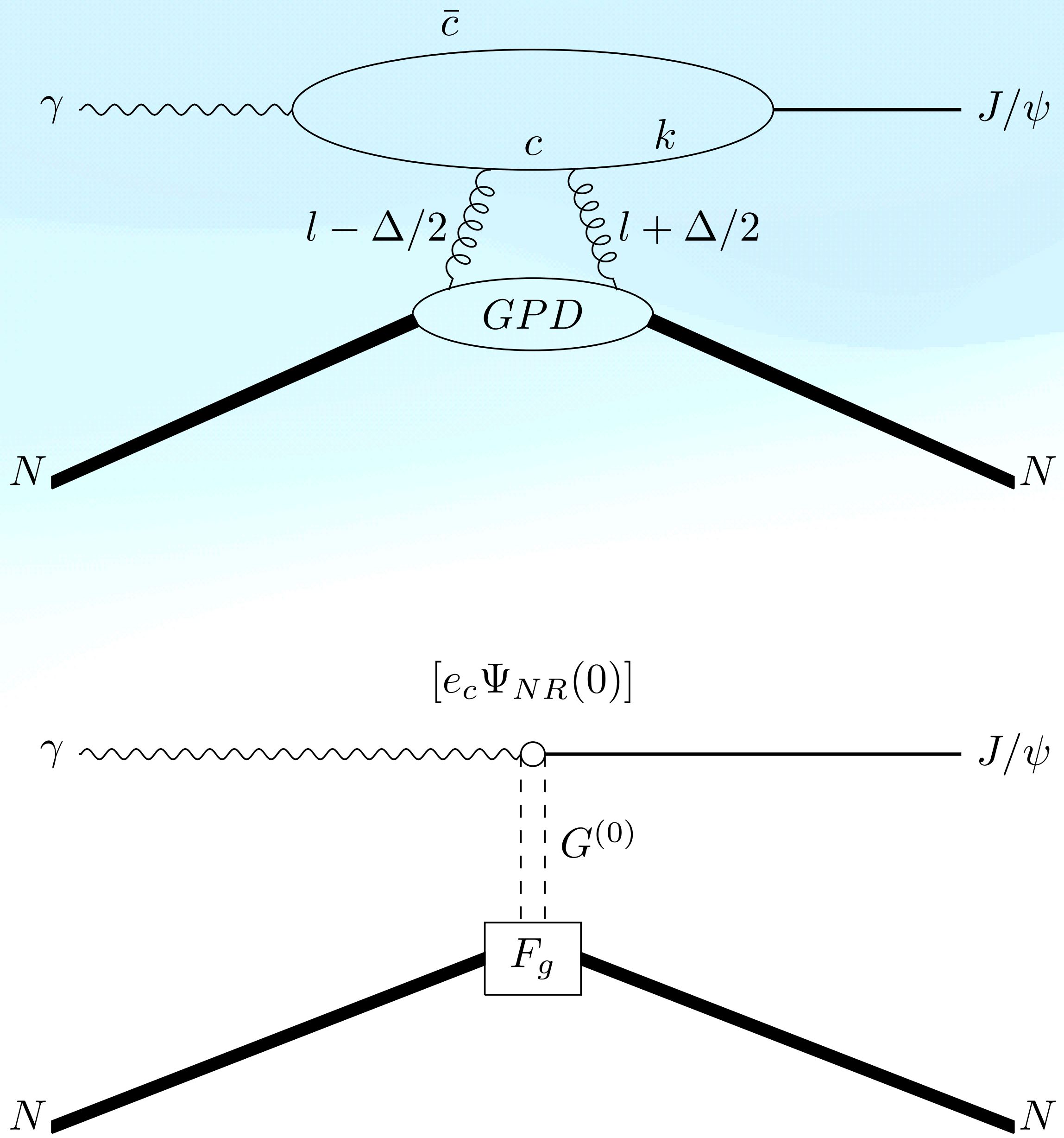
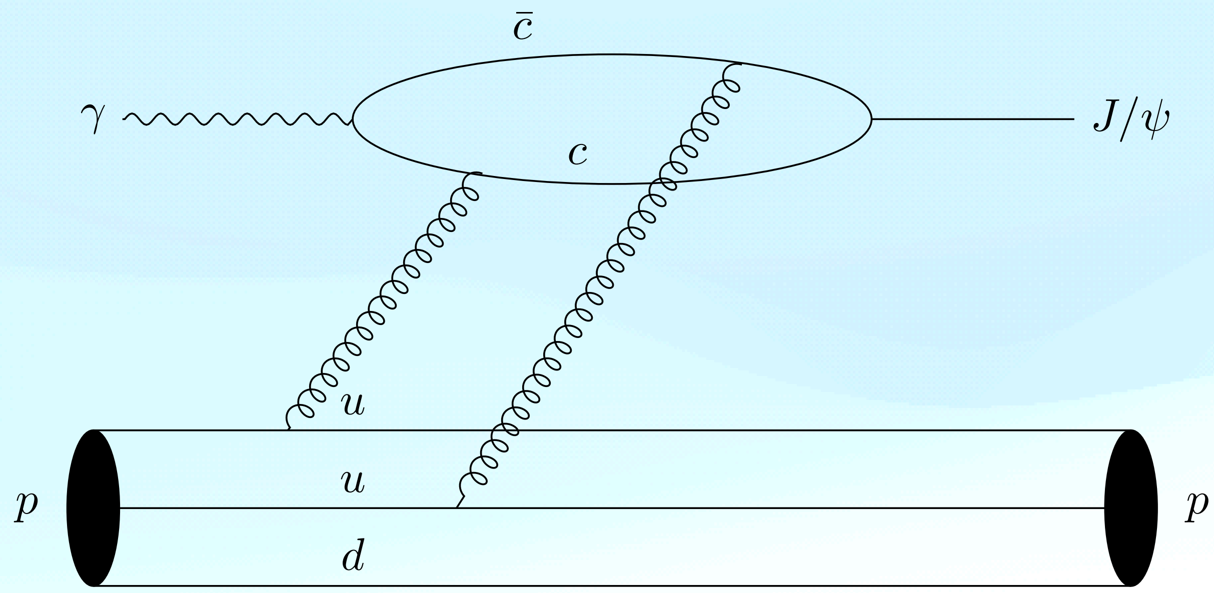


Fig. 4 *GPD*-based model. Upper: One of the four two-gluon exchange diagrams of Eq. (5), Lower: The amplitude of Eq. (6).

Model IV



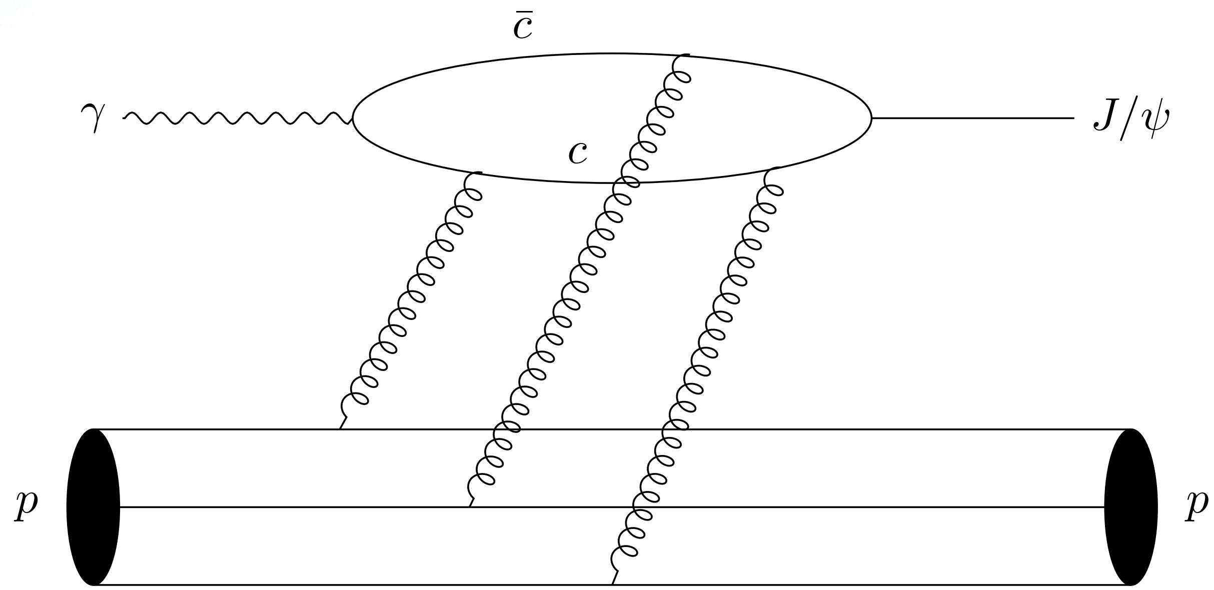


Fig. 5 The $2g + 3g$ model. Upper: two-gluon exchange, Lower: three-gluon exchange.

Model V

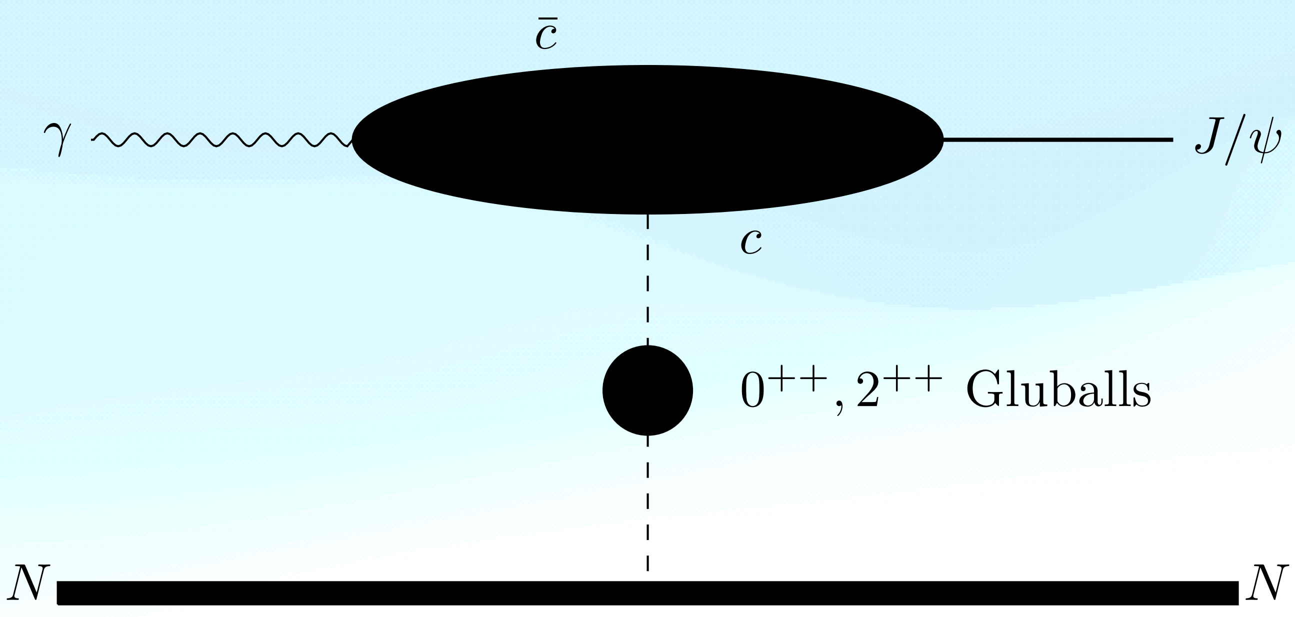


Fig. 6 The holographic model.

Exchanges of scalar (0^+) and tensor (2^+) gluebells

Model VI

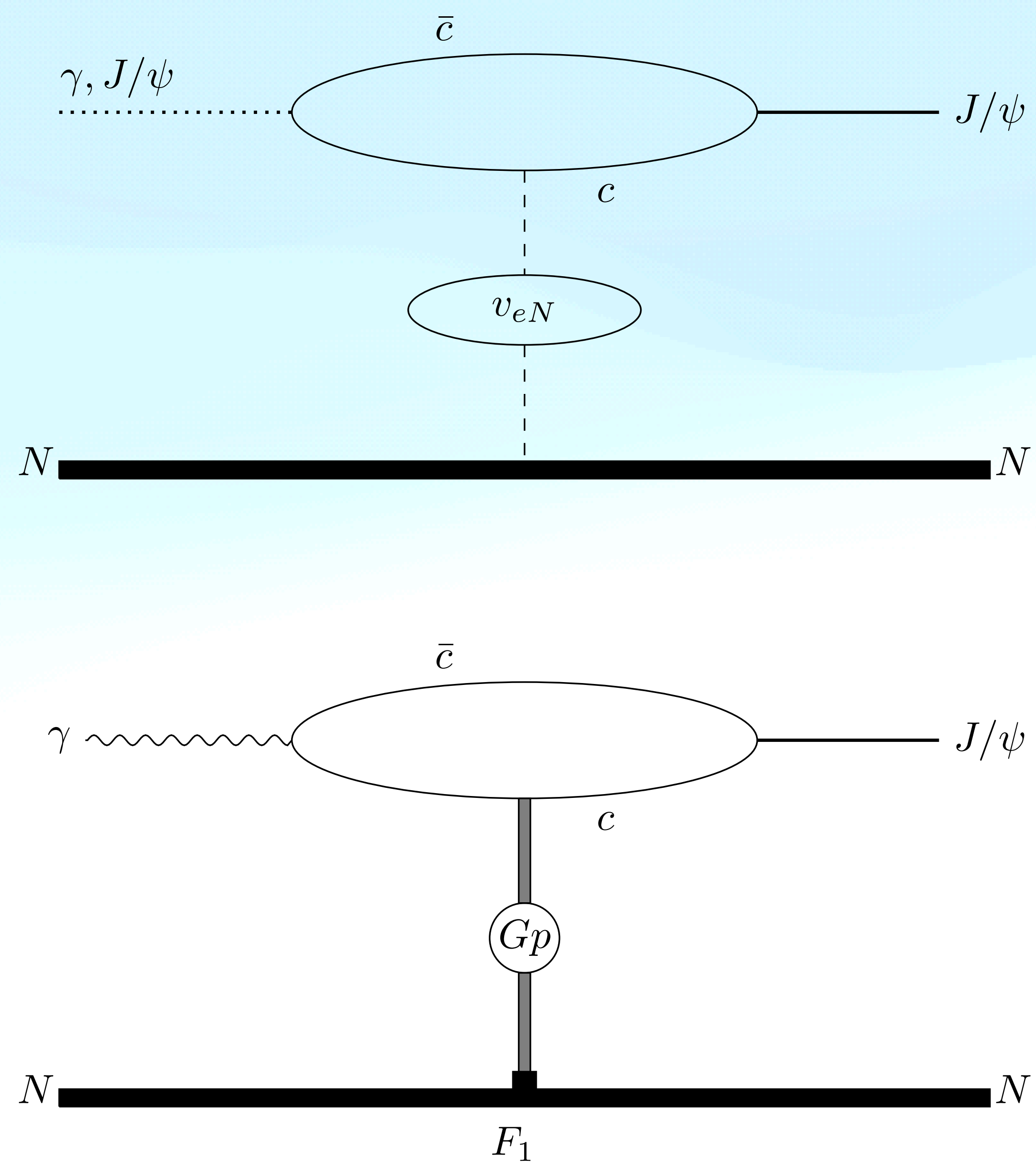


Fig. 7 Models with $c\bar{c}$-loop mechanisms. Upper: calculated from quark-nucleon potential (v_{cN}), Lower: calculated from Pomeron-exchange mechanism.

Model II

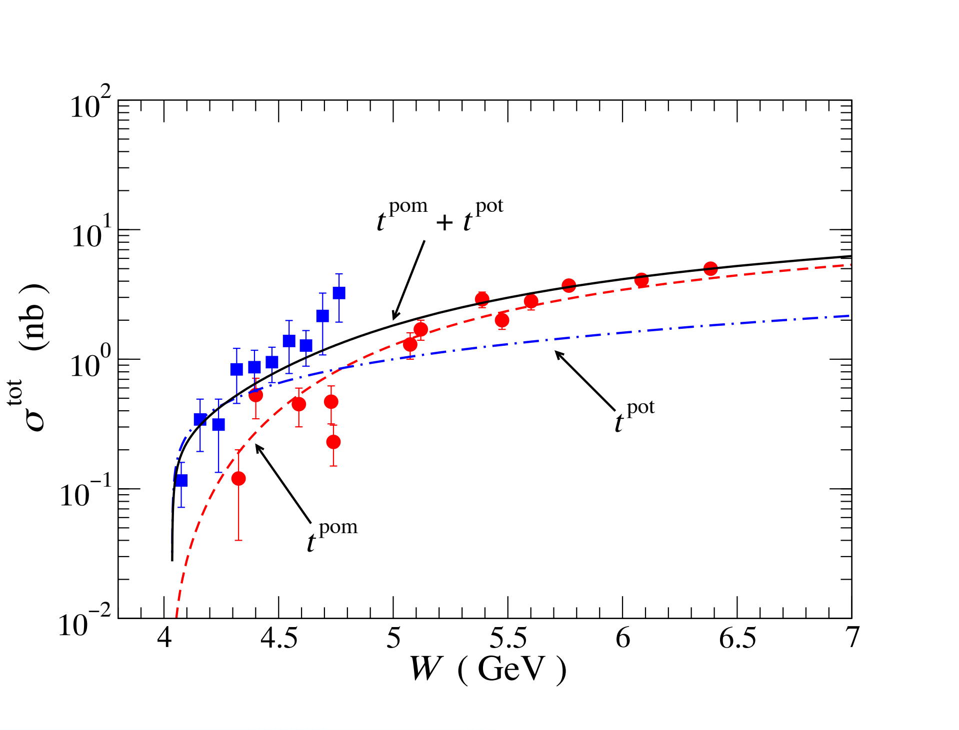


Fig. 14 The total cross sections of $\gamma + p \to J/\Psi + p$. t^{Pom} (t^{pot}) indicates the cross sections calculated from keeping only t^{Pom} (t^{pot}) term in Eq. (38). $t^{\text{Pom}} + t^{\text{pot}}$ indicate the cross sections calculated from the total amplitude.

Model III

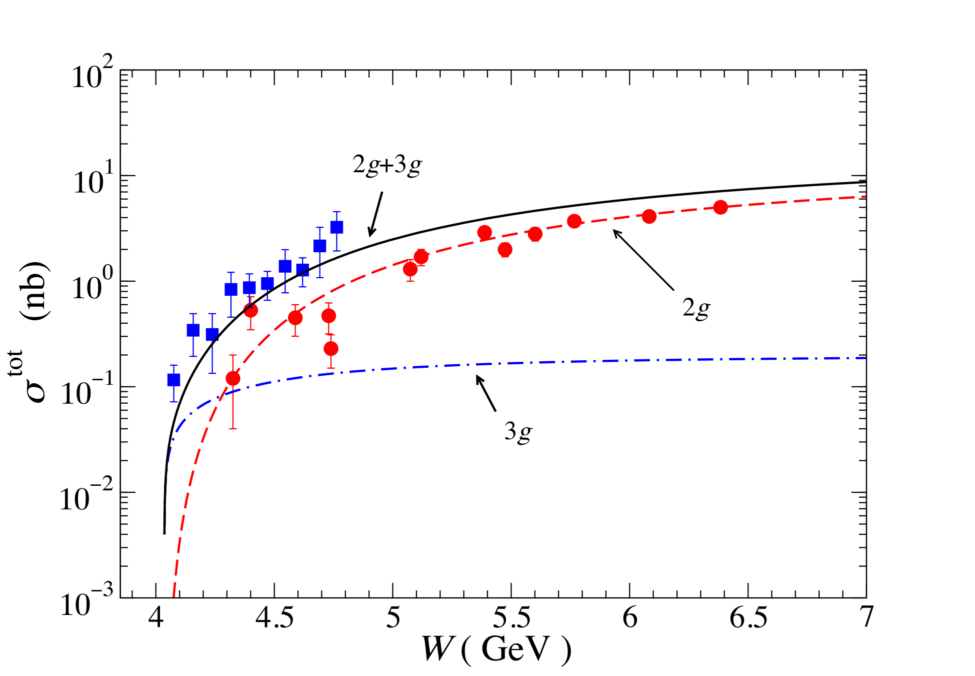
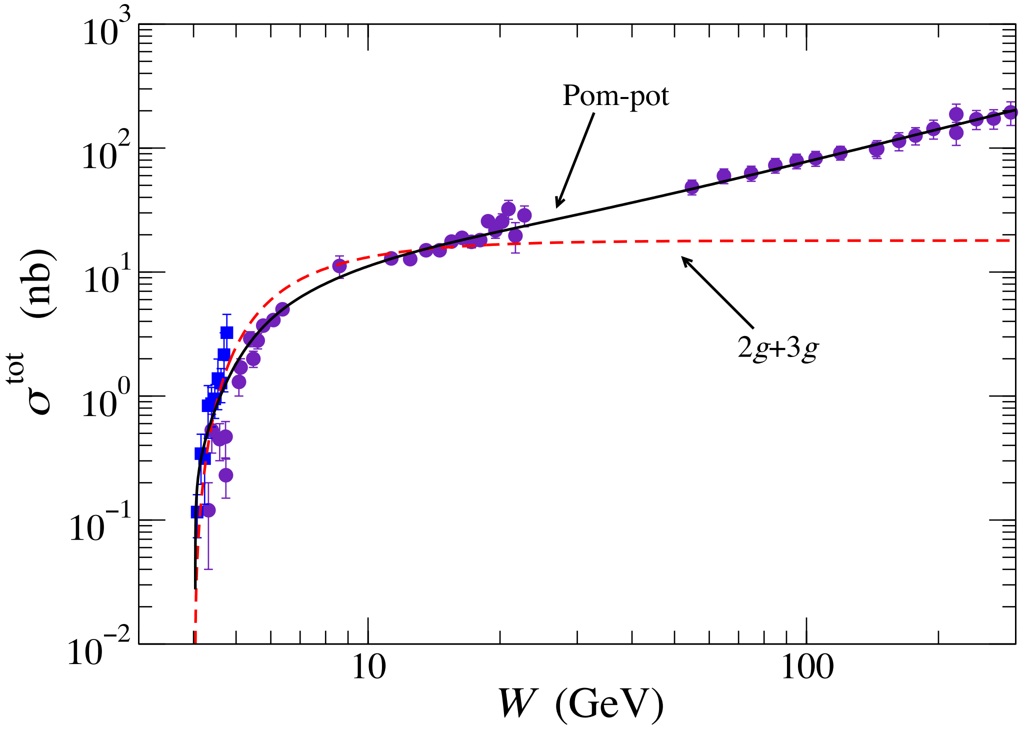
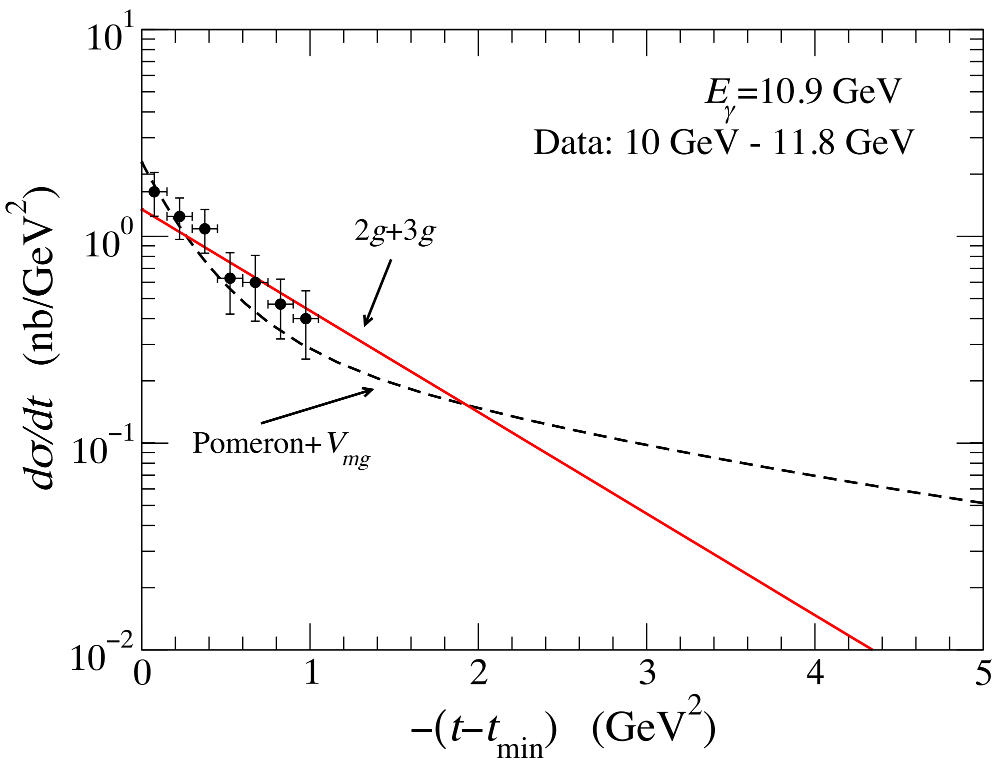


Fig. 16 Total cross sections of $\gamma + p \to J/\Psi + p$ calculated from $2g + 3g$ model. $2g$ ($3g$) is the contribution from two-gluon (three-gluon) exchange amplitudes of Eq. (46).

Model II vs Model III





Model IV

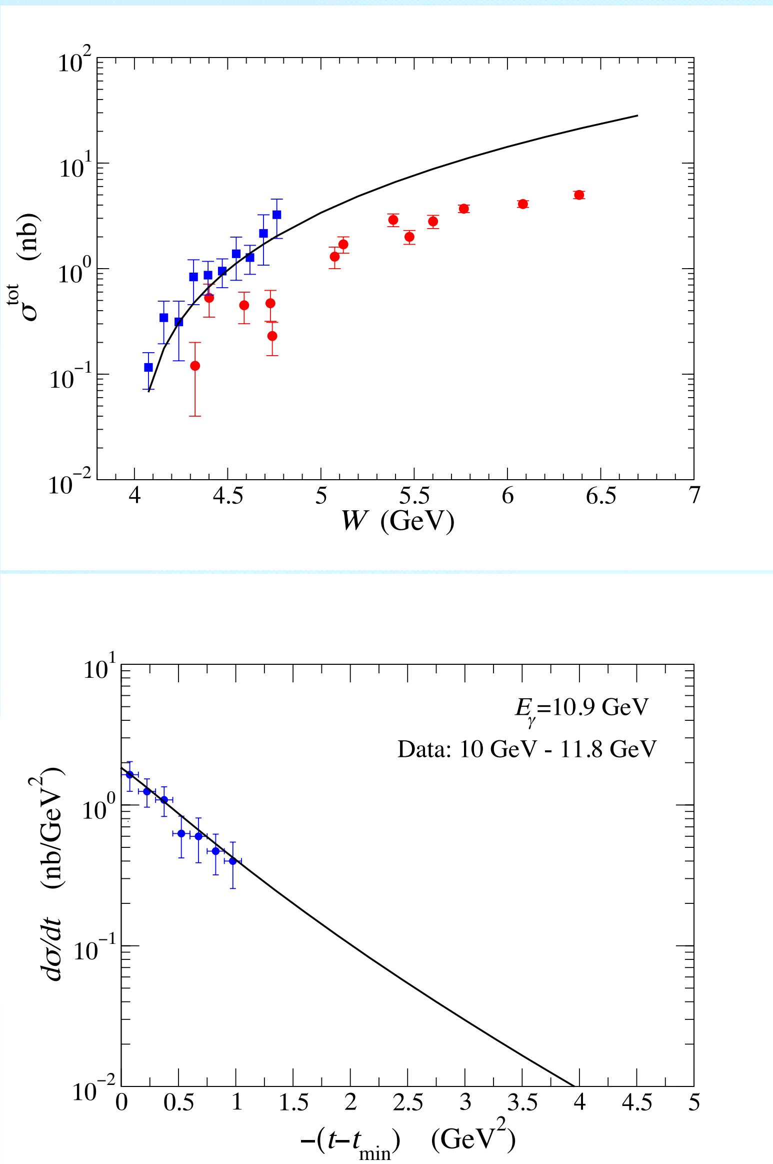


Fig. 19 *GPD*-based model. Upper: total cross sections, Lower: differential cross sections.

Model V

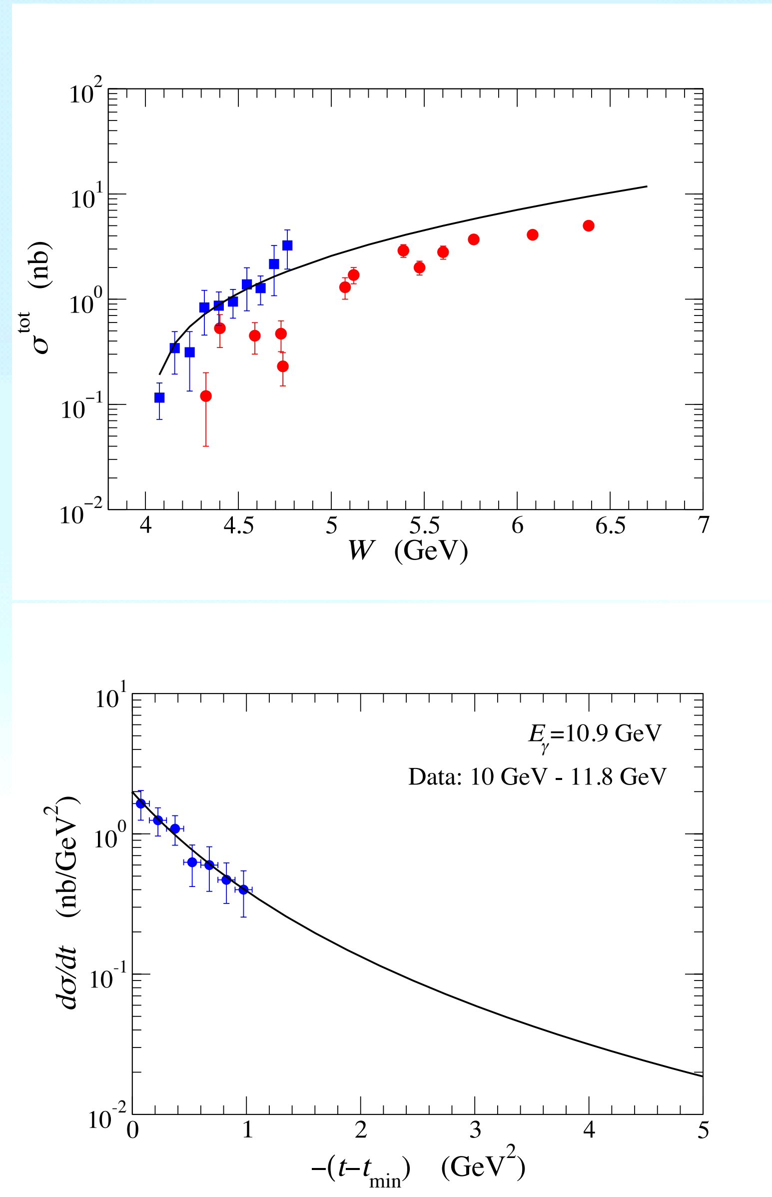


Fig. 20 *Holog* model. Upper: total cross sections; Lower: differential cross sections.

Model VI

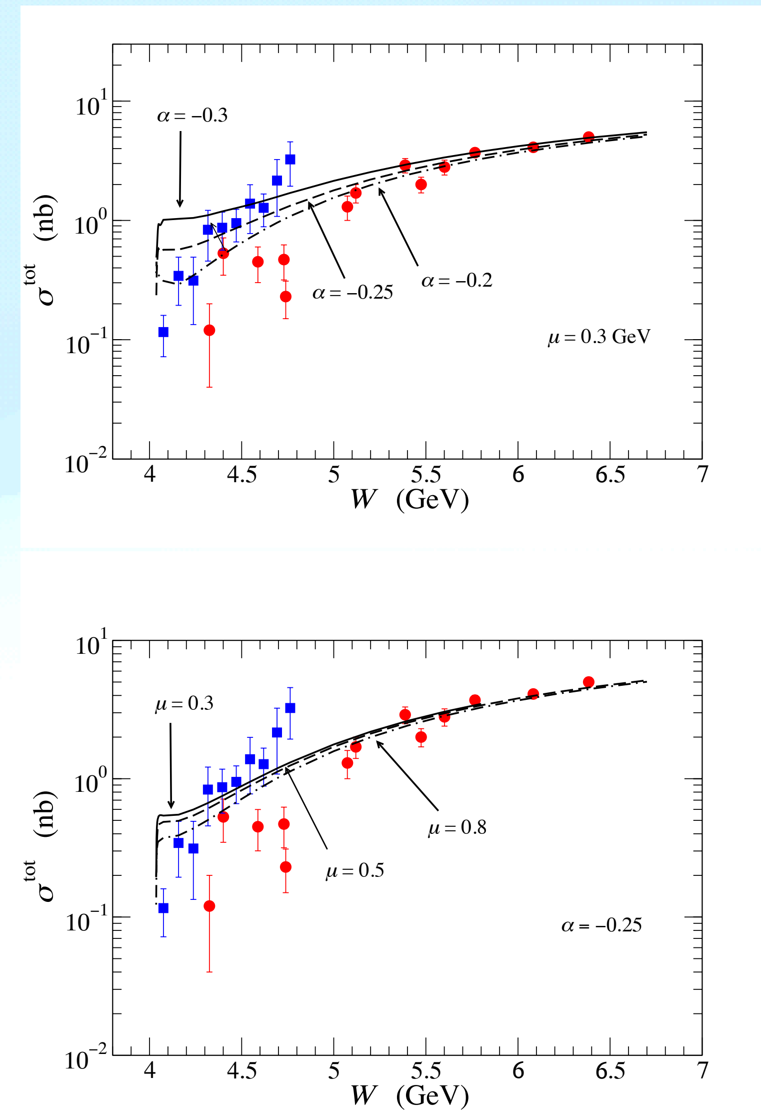


Fig. 27 Dependence of the total cross sections on the parameter α (upper) and μ (lower) of the quark-nucleon potential $v_{cN} = \alpha \frac{e^{-\mu r}}{r}$ within the *Pom*-CQM model.

N* Contribution

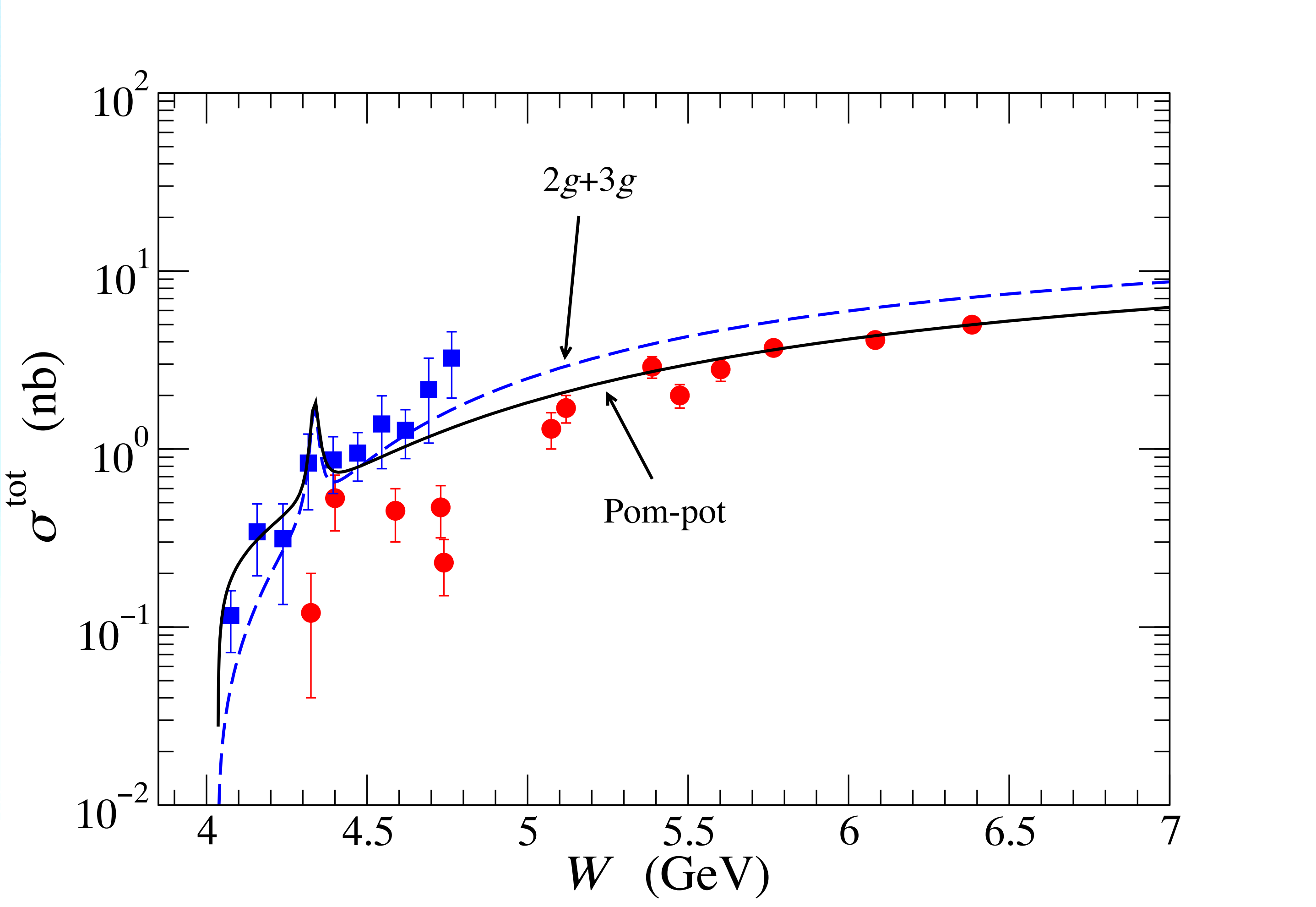


Fig. 21 Fits to the total cross section data of $\gamma + p \rightarrow J/\Psi + p$. The $P_c(4337)$ ($J^\pi(LS) = \frac{1}{2}^-(0, \frac{1}{2}1)$, $A_{1/2} = 1 \times 10^{-3}$ GeV^{-2}) is included in the fits with the non-resonant amplitudes calculated from either the *Pom*-pot (solid curve) or $2g + 3g$ (dashed curve) models.

Summary

- In the near threshold region, all models for J/ψ photo-production can describe the available Jlab data equally well, but give rather large differences at large momentum-transfer and in the very near threshold region.

These observations lead to

1. Each model needs improvements for determining N*.
2. Need high precision data at large momentum-transfer and very close to threshold.
3. More detailed and complete understanding of the models is needed to distinguish them. (Spin polarization?)

Thank you