A Unified Framework Across Multi-Experiment Hadron Physics Programs: J-PARC and JLab

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The George Washington University

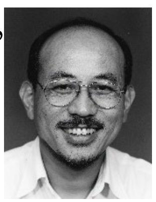
- Once upon a time, there was a Vector Meson....
- JLab for Threshold J/ψ Photoprod on Proton.
- Phenomenology for VN SL.
- VMD Model.
- Nucleon Formfactor.
- Vector Meson Nucleon SL Puzzle.
- Perturbative QCD Effect.
- SU(3) : from Omega to Phi.
- Nanjing & Bonn Us, for J/ψ p SL.
- J-PARC for J/ψ & ϕ Production at Threshold.
- Polarization of Quarkonium.
- Plausibility of Heavy 5q in GlueX Data.
- Summary.

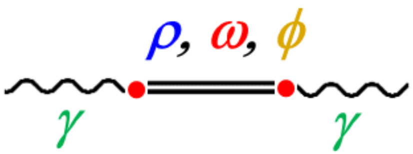
Supported by DE-SC0016583


NSTAR 2026
Once upon a Time, there
was a Vector Meson. . .

- There are no *vector meson beams*, so modern experiments using EM & hadronic facilities attempt to access *vector meson – nucleon* interactions via EM $\mathbf{e + p \to e' + V + p}$ & hadronic $\mathbf{\pi^- + p \to V + n}$ production reactions.

- Moreover, vector mesons ρ, ω, & ϕ play central role in *Sakurai's* VMD model, where they account for (*virtually admixed*) hadronic part of photon by which photon couples to hadronic matter. J.J. Sakurai, Ann Phys (NY) **11**, 1 (**1960**)

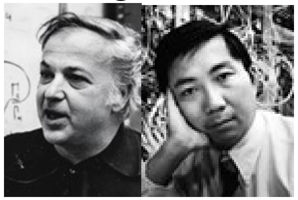




- "*November Revolution*" or discovery of *heavy vector meson* J/ψ **50** years ago @ & SLAC opened access to new $\bar{c}c$ system.

  @ West coast of US J.J. Aubert *et al*. Phys Rev Lett **33**, 1404 (**1974**)

  @ East coast of US J.-E. Augustin *et al*. Phys Rev Lett **33**, 1406 (**1974**)

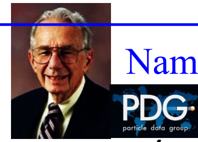


Vector Meson Zoo

- Some *vector mesons* can, compared to other mesons, be measured to very high precision.
- This stems from fact that *vector mesons* have ***same*** quantum numbers as *photon*.
- Let us focus on **4** ***vector mesons*** from $\bar{q}q$ ***nonet*** to study *meson photoproduction* @ threshold & where data are available.

$(J^{PC}) = (1^{--})$

J – spin, **P** *- parity*
C *- charge conjugation*



Name	Quark Content	Γ_{tot} (MeV)
$\rho^+(770)$	$u\bar{d}$	148
$\rho^0(770)$	$\frac{1}{\sqrt{2}}(u\bar{u}-d\bar{d})$	149
$\omega(782)$	$\frac{1}{\sqrt{2}}(u\bar{u}+d\bar{d})$	8.5
$K^{*+}(892)$	$u\bar{s}$	51
$K^{*0}(892)$	$d\bar{s}$	47
$\phi(1020)$	$\bar{s}s$	4.3
$D^+(1870)$	$c\bar{d}$	6.3×10^{-10}
$D^0(1865)$	$c\bar{u}$	1.6×10^{-9}
$D^{*+}(2010)$	$c\bar{d}$	0.083
$D^{*0}(2007)$	$c\bar{u}$	0.055
$J/\psi(1S)(3097)$	$\bar{c}c$	0.093
$\psi'(2S)(3686)$	$\bar{c}c$	0.284
$\Upsilon(1S)(9460)$	$b\bar{b}$	0.052
$T(1S)(?)$	$t\bar{t}$	?

SL(ρ) may be partly spoiled by large $\Gamma(\rho)$. Besides this, it may be affected by Δ. That is likely why **SL**(ω) ~ 4 **SL**(ρ).

Open Charm ← No **VMD**

Hidden Charm

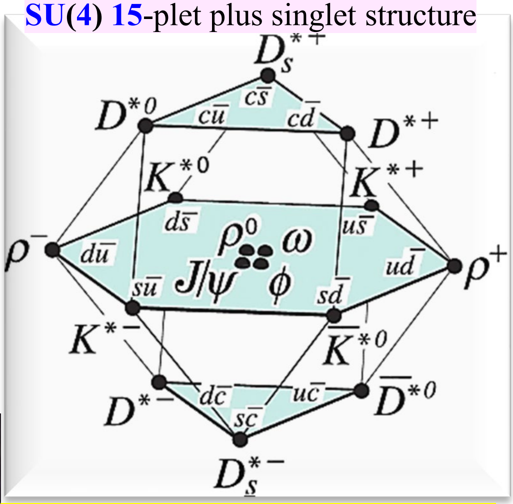
There is difference between **1S** & **2S** states due to `*zero*' in radial **WF**s.

Bottonium

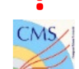
Toponium

It does not exist because large mass & **t**-quark decay faster than meson formation time.

SU(4) 15-plet plus singlet structure



J.J. de Swart, Rev Mod Phys **35**, 916 (**1963**)



gave $t\bar{t}$ pair with rather strong final state interaction.

A. Hayrapetyan *et al*, Rep Prog Phys **88**, 127801 (**2025**)

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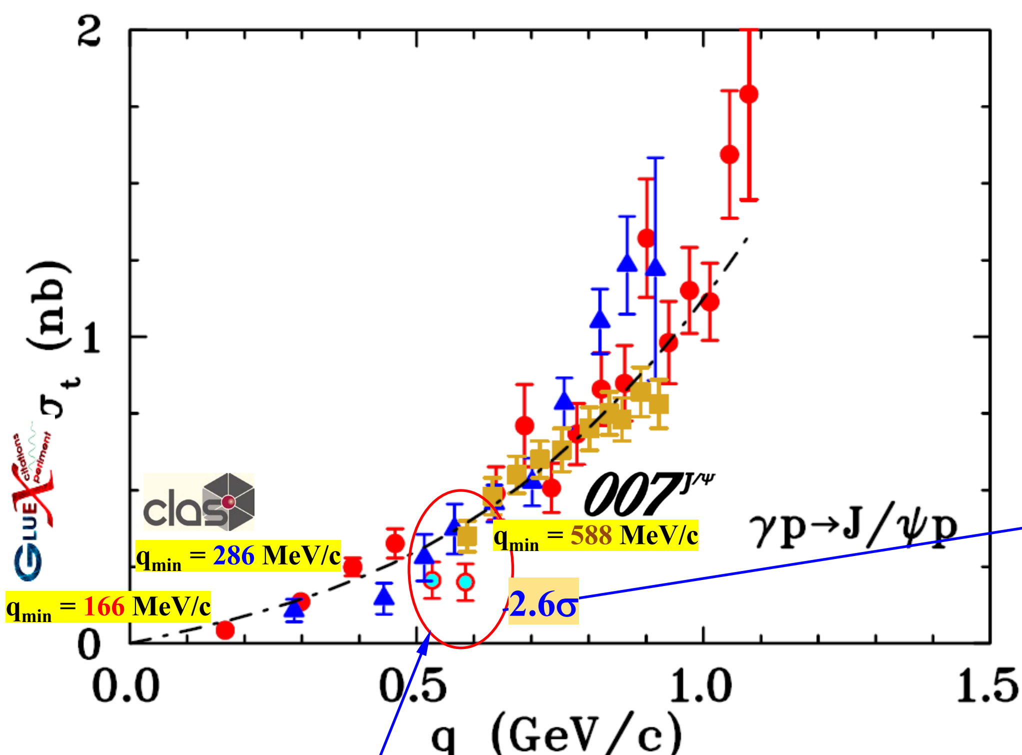
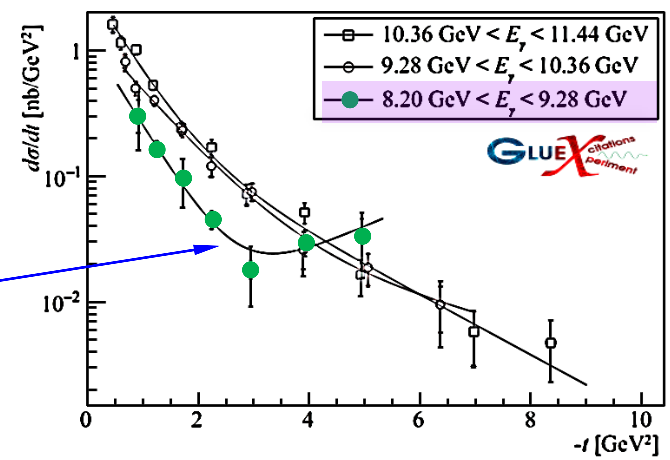
JLab for Threshold J/ ψ Photoproduction on Proton

Jefferson Lab *Total Cross Sections for Vector Meson Photoproduction Contribution for SL*

IIS, J.K. Ahn, W.J. Briscoe, M.G. Ryskin, & A. Schmidt, Phys Rev D **113**, 114023 (2026)





S. Adhikari *et al*, Phys Rev C **108**, 025201 (2023)

While 007$^{J/\psi}$ data lacks coverage in **q** to make firm statement about existence of **dip**, more recent clas electroproduction data *do not show* evidence of **dip**. Still, uncertainties are very large (low statistics) to solve this puzzle.

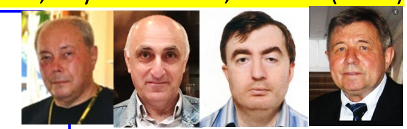
- **Two** exponential functions fit Xsec.
- **Second** exponential contribution is most significant in *lowest energy bin*, where slope *changes sign*.

- Agreement between all three J/ψ data sets GlueX 007$^{J/\psi}$ clas shows no indication of systematic differences between methodologies.

Phenomenology for Vector Meson Nucleon Scattering Length

Vector Meson – Nucleon SL Determination

IIS, D. Epifanov, & L. Pentchev, Phys Rev C **101**, 042201 (2020)
IIS, L. Pentchev, & A.I. Titov, Phys Rev C **101**, 045201 (2020)



- Small *positive* or *negative VN SL* may indicate weakly *repulsive* or *attractive VN* interaction if there is no *VN* bound state below experimental q_{min}.
- For evaluation of *absolute* value of *VN SL*, we apply *VMD* approach that links near-thr photoprod *Xsections* of $\gamma p \to Vp$ & elastic $Vp \to Vp$

$q \to 0$

$$\frac{d\sigma^{\gamma p\to Vp}}{d\Omega}\Big|_{thr} = \frac{q}{k}\frac{1}{64\pi}|T^{\gamma p\to Vp}|^2 = \frac{q}{k}\cdot\frac{\pi\alpha}{g_V^2}\frac{d\sigma^{Vp\to Vp}}{d\Omega}\Big|_{thr} = \frac{q}{k}\cdot\frac{\pi\alpha}{g_V^2}|\alpha_{Vp}|^2$$

V CM momentum

Photon CM momentum

$k = (s - M^2) / 2\, s^{1/2}$

Invariant amplitude of *V* photoproduction

$$g_V^2 = \frac{\pi\cdot\alpha^2\cdot m_V}{3\cdot\Gamma(V\to e^+e^-)}$$

Fine-structure constant

VMD coupling constant, related to *V EM* decay width $\Gamma(V\to e^+e^-)$

- Absolute value *SL* is determined by interplay of *strong* (*hadronic*) & *EM* dynamics as:

$$\boxed{|\alpha_{VN}|^2 = (h\,B)^2}$$

where *hadronic* component is $\boxed{h^2 = a}$ & *linear term* **a** came from $\boxed{\sigma_t = a\, q + b\, q^3 + c\, q^5}$ Experiment

pure ***EM VMD***-motivated kinematic factor $\boxed{B^2 = \frac{\alpha}{12\pi}\,\frac{m_v\, k_{thr}}{\Gamma(V\to e^+\, e^-)}}$ PDG

- For VN system, to avoid theor uncertainties, we do not
  - Determine *sign* of ***SL***,
  - Separate Re & Im *parts* of ***SL***,
  - Extract *total angular momentum* 1/2 & 3/2 contributions

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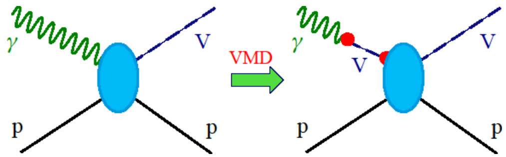
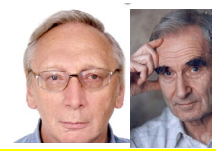
VMD Model



VMD for VN Interaction

- **ρp** & **ωp** ***SL*** were determined from photoprod reactions **γp→Vp** with *VDM*.
  Non-perturbative QCD-related approach employing dressed quarks & gluons as ingredients for **γp→Vp** reaction model is under development in

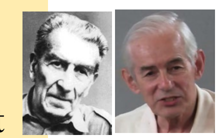


- To estimate theoretical uncertainty related to *VMD* model, one refers to estimation of Xsec of **J/ψ** photoproduction in *peripheral model* & found strong energy dependence close to threshold because non-diagonal **γp→Vp** & elastic **Vp→Vp** must have larger transfer momenta *vs* elastic scattering. This results in violation of *VMD* by factor of **5**.

K.G. Boreskov & B.L. Ioffe, Sov J Nucl Phys **25**, 331 (**1977**)

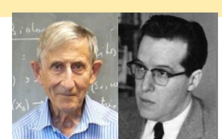
- **Color** factor for *hidden charm* is **1/9**, while for *open charm* is **8/9**.

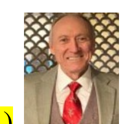
B.Z. Kopeliovich, I. Schmidt, & M. Siddikov, Phys Rev C **95**, 065203 (**2017**)



- Strong suppression in *VN* interaction close to thr is observed because of $Q\bar{Q}$ pair in point-like configuration lacks sufficient time to form complete wave function of *vector meson*; that is, proton interacts with "*young*" (undressed quarks) *vector meson* whose size is smaller than that of "*old*" one participating in elastic ***Vp→Vp*** scattering.

E.L. Feinberg, Sov Phys Usp, **23**, 629 (**1980**)
Courtesy of Misha Ryskin, July **2020**





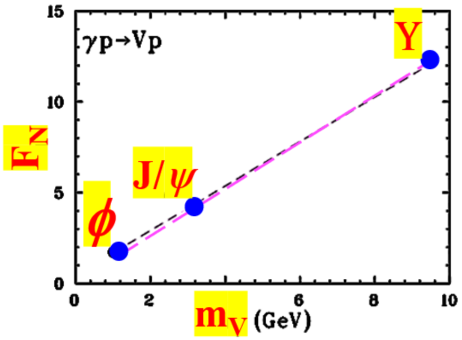
- In recent study, effect of *VMD* assumption was studied in formalism of *Dyson-Schwinger equations,* which one can consider alternative interpretation of "*young age*" in connection to QCD.

Y.Z. Xu, S. Chen, Z.Q. Yao, D. Binosi, Z.F. Cui, & C.D. Roberts, Eur Phys J C **81**, 895 (**2021**)

Nucleon Formfactor

Vector Meson SL Accounting Nucleon FF

IIS, J.K. Ahn, W.J. Briscoe, M.G. Ryskin, & A. Schmidt, Phys Rev D **113**, 114023 (2026)



$$F_N(t) = \frac{1}{1 - t/\Lambda^2}$$

Meson	Photoproduction SL (fm)	$-t_{min}$ (GeV^2)	$SL/F_N(t)$ (fm)	pQCD (fm)	dynSL (fm)
ϕ	0.063±0.010 [14]	0.50	0.109±0.017	0.065	0.123
J/ψ	0.00274±0.00027†	2.22	0.0113±0.0011	0.0029	0.00634
Υ	0.00051±0.00003 [17]	8.07	0.0063±0.0004	0.00047	0.00196

- **Finally**, recall that actually we deal with $Q\bar{Q}$ -proton interaction & not with elastic **Vp → Vp** scattering.
- Size of this pair, produced by point-like photon, is smaller than normal **V** size.
- Thus, it is natural to expect smaller Xsec. This "*young effect*" explains relatively small values of SL measured in photoprod.

- In photoproduction, $Q\bar{Q}$ pair is produced @ point (locally) by *point-like photon*, & heavy quarks do not have sufficient time to fly away @ distances corresponding to normal size of **V** wave function.
- **That is**, actually, we deal with small-sized $Q\bar{Q}$ pair-proton interaction & not with normal **Vp** scattering.
- **On other hand**, within pQCD, corresponding Xsec σ($Q\bar{Q}$+p) ∝ r^2, where **r** is $Q\bar{Q}$ separation.
- Indeed, small size (***young***) colorless object is almost sterile with respect to QCD interaction.
- Therefore, ***SL***, *ie*, Xsec measured in photo(electro)prod, is smaller than that for Vp → Vp interaction.

- Recall that, strictly speaking, to measure **SL** of **V**-proton interaction, we have to consider not **V** photoprod but **V** elastic scattering on proton.
- In comparison with elastic process in case of photoprod, we have *three* additional factors that may depend on $\mathbf{m_V}$.

- We have to emphasize that to produce heavy **V** @ thr, we need to have rather large momentum transferred **t**.

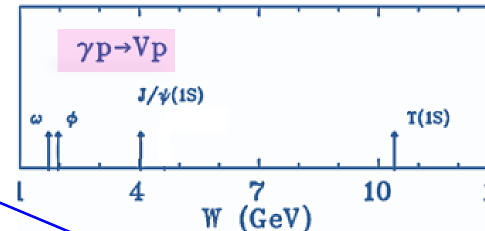
Vector Meson Nucleon Scattering Length Puzzle

Can Young Hypothesis Explain Vector Meson – Nucleon SL Puzzle ?

IIS, J.K. Ahn, W.J. Briscoe, M.G. Ryskin, & A. Schmidt, Phys Rev D **113**, 114023 (**2026**)

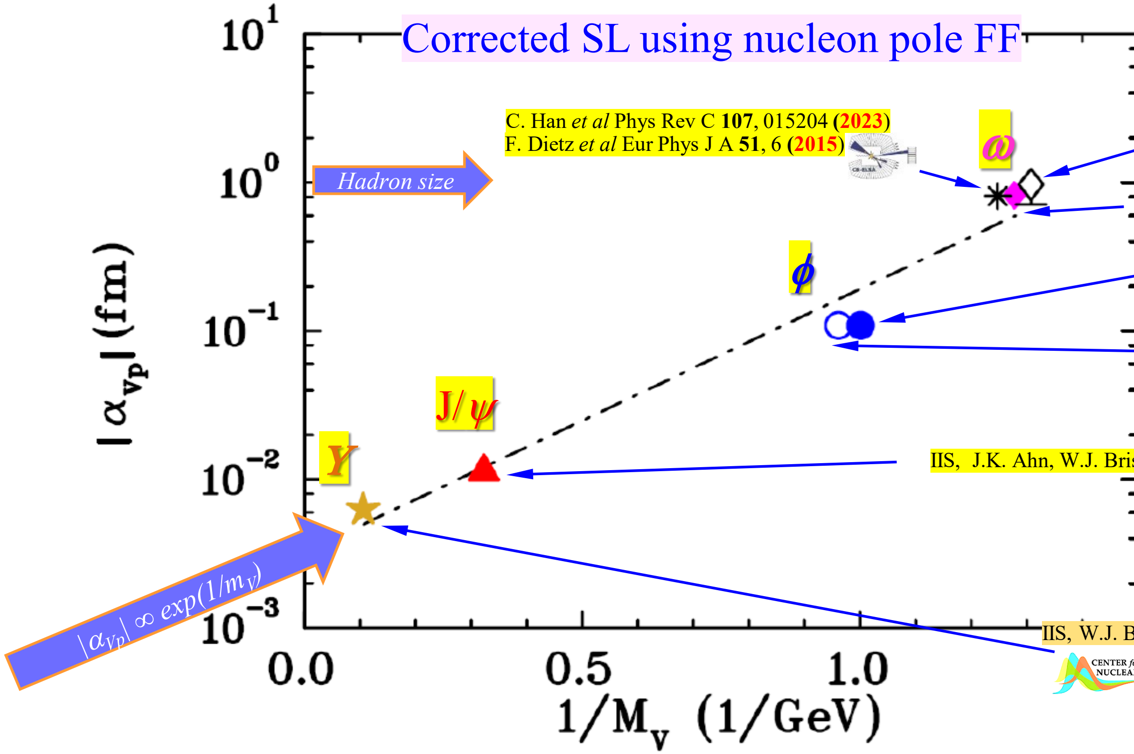
- Due to ***small size*** of "*young*" V vs "*old*" V, measured & predicted ***SL*** is very small.
- V created by photon @ threshold then most probably V is not *formed completely* & its radius is smaller than that for normal ("*old*") V.
- Therefore, one observes stronger suppression for ***Vp*** interaction.

$|\alpha_{\Upsilon p}| << |\alpha_{J/\psi p}| << |\alpha_{\phi p}| << |\alpha_{\omega p}|$



E.L. Feinberg, Sov Phys Usp, **23**, 629 (**1980**)

Courtesy of Misha Ryskin, July **2020**



C. Han *et al* Phys Rev C **107**, 015204 (**2023**)
F. Dietz *et al* Eur Phys J A **51**, 6 (**2015**)

T. Ishikawa *et al*, Phys Rev C **101**, 052201(R) (**2020**)

IIS, S. Prakhov, Ya. Azimov *et al*, Phys Rev C **91**, 045207 (**2015**)

IIS, L. Pentchev, & A.I. Titov, Phys Rev C **101**, 045201 (**2020**)
B. Dey *et al*, Phys Rev C **89**, 055208 (**2014**)

C. Han *et al* Phys Rev C **107**, 015204 (**2023**)
W.C. Chang *et al*, Phys Lett B **658**, 209 (**2008**)
T. Mibe *et al*. Phys Rev Lett **95**, 182001 (**2005**)

IIS, J.K. Ahn, W.J. Briscoe, M.G. Ryskin, & A. Schmidt, Phys Rev D **113**, 114023 (**2026**)
S. Adhikari *et al*, Phys Rev C **108**, 025201 (**2023**)
S. Joosten *et al*, arXiv:**2602**.14416 [nucl-ex]
P. Chatagnon *et al*. Phys Rev C **113**, 065203 (**2026**)

IIS, W.J. Briscoe, L. Pentchev, & A. Schmidt, Phys Rev C **104**, 074028 (**2021**)
Y. Guo, X. Ji, & Y. Liu, Phys Rev D **103**, 096010 (**2021**)

- ***p→V*** coupling $\bar{q}q$ is proportional to a_s & *separation* of corresponding quarks.
- This *separation* (in *zero approximation*) is proportional to $1/m_V$.

Perturbative QCD Effect

pQCD for *VN SL*

IIS, J.K. Ahn, W.J. Briscoe, M.G. Ryskin, & A. Schmidt, Phys Rev D **113**, 114023 (2026)

- Our analysis shows almost linear (on exponential scale) increase in $|\alpha_{Vp}| \propto \exp(1/m_V)$ with increasing $1/m_V$.
- This is interesting observation; however, behavior ***does not satisfy expected asymptotic***

$$\alpha_{Vp} \to 0 \text{ as } m_V \to \infty.$$

- In fact, in *pQCD*, $p \to V$ coupling is proportional to strong coupling α_s & separation of corresponding quarks.
  This separation (in zero approximation) is proportional to $1/m_V$, or $1/m_Q$, where m_Q is *current* quark mass.

- Taking *current* quark masses PDG as $m_s = 0.1$ GeV, $m_c = 1.3$ GeV, & $m_b = 4.2$ GeV, along with constant $\Lambda = 350$ MeV, & inserting

$$\alpha_{Vp} = 1/30\ 0.197[\text{fm} \cdot \text{GeV}]\ \alpha_s(m_Q) / m_Q$$

  with ***one-loop*** $\alpha_s = (4\pi/b_0)/\ln(m_Q^2/\Lambda^2)$,
  but if $\alpha_s > 1$, then $\alpha_s = 1$ (*ie*, α_s is frozen @ 1; & b_0 is referred to as *one-loop* β-function coefficient $b_0 = 8.33$ for 4 light quarks: u, d, s, & c).

Meson	Photoproduction SL (fm)	$-t_{min}$ (GeV^2)	SL/$F_N(t)$ (fm)	pQCD (fm)	dynSL (fm)
ϕ	0.063±0.010 [14]	0.50	0.109±0.017	0.065	0.123
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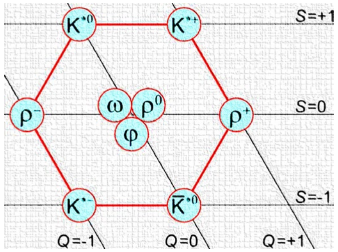
- Of course, expression is not real ***perturbative*** *QCD* calculations. This is just *naive estimate*. However, it demonstrates that observed SLs are consistent with ***perturbative*** *QCD* & account for suppression due to *young* effect.

- Recall that aim of our project is not to build model that describes data, but phenomenological analysis. (Model(s) & corresponding theoretical uncertainties can be found, *eg*, in &

SU(3): from Omega to Phi



$SU(3)_F$ *for* *VN* *SL*

IIS, J.K. Ahn, W.J. Briscoe, M.G. Ryskin, & A. Schmidt, Phys Rev D **113**, 114023 (**2026**)

***Vector-meson* nonet** is $\rho(770)$, $K^*(892)$, $\omega(782)$, $\phi(1020)$
with *multiplicities:* $3\rho + 4K^* + 1\omega + 1\phi = 9$

- Actually, paper by Titov *et al*. gives relationship between **SL**s of ϕN & ωN using $SU(3)_F$ symmetry:

$$|\alpha_{\phi N}| = \epsilon\, |\alpha_{\omega N}|$$

where

$$\epsilon \equiv -\mathrm{tg}(\Delta\theta_V) \quad \& \quad \Delta\theta_V \simeq 3.7^0$$

represents ***deviation of ϕ-ω mixing angle*** from ***ideal mixing angle***.
(Vector mixing angle $\theta_V = 36.5^0$ is very close to ***ideal mixing angle***. PDG)

A.I. Titov, T. Nakano, S. Date, & Y. Ohashi, Phys. Rev. C **76**, 048202 (**2007**).

This relation assumes that **SL** originates from *light* (**u**,**d**) quarks only, most likely from nucleon resonances.

- Ratio of our phenomenological **SL** determination

$|\alpha_{\omega N}| = 0.82$ fm — IIS, S. Prakhov, Ya. Azimov *et al*, Phys Rev C **91**, 045207 (**2015**)

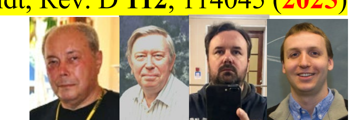
$|\alpha_{\phi N}| = 0.063$ fm — IIS, L. Pentchev, & A.I. Titov, Phys Rev C **101**, 045201 (**2020**)

corresponds to $\Delta\theta_V \simeq 4.4^0$

- In $SU(3)_F$, there should be similar relation for $|\alpha_{\phi N}|$ with $|\alpha_{\omega N}|$ & $|\alpha_{\phi N}|$ with $|\alpha_{\rho N}|$.
However, for ρ, it may be partly spoiled by large ρ *width*.
Besides this, in ρp case, result may be affected by ***isobars*** ($I = 3/2$).

IIS, E. L. Isupov, V. Mokeev, & A. Schmidt, Rev. D **112**, 114045 (**2025**)

That is likely why $|\alpha_{\omega N}| \simeq 4\, |\alpha_{\rho N}|$, as was reported recently.

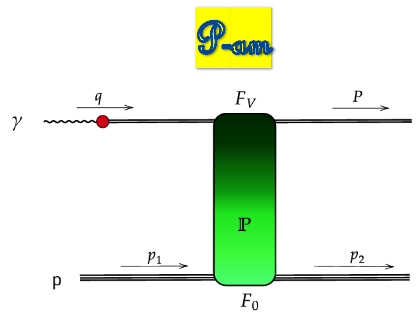


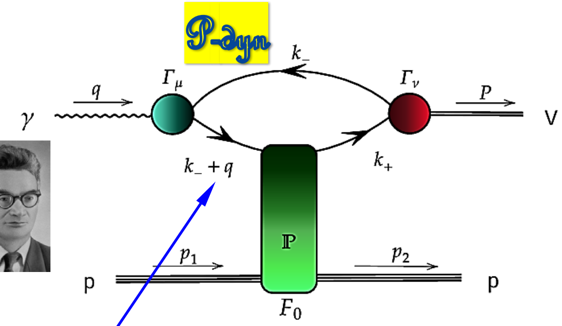
Nanjing & Bonn Us for J/ψ–P SL

for *VM Photoproduction*

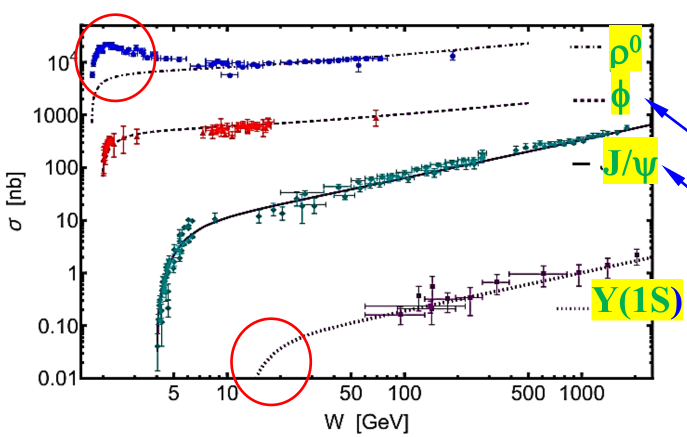
Abstract A reaction model for $\gamma + p \to V + p$, $V = \rho^0, \phi, J/\psi, \Upsilon$, which exposes the quark-antiquark content of the photon in making the transition $\gamma \to q\bar{q} + \mathbb{P} \to V$, where q depends on V, and couples the intermediate $q\bar{q}$ system to the proton's valence quarks via Pomeron ($\mathbb{P}$) exchange, is used to deliver a unified description of available data – both differential and total cross sections – from near threshold to very high energies, W, for all the V-mesons. For the Υ, this means $10 \lesssim W/\text{GeV} \lesssim 2000$. Also provided are predictions for the power-law exponents that are empirically used to characterise the large-W behaviour of the total cross sections and slope parameters characterising the near-threshold differential cross sections. Appealing to notions of vector meson dominance, the latter have been interpreted as vector-meson–proton scattering lengths. The body of results indicate that it is premature to link any $\gamma + p \to V + p$ data with, for instance, in-proton gluon distributions, the quantum chromodynamics trace anomaly, or pentaquark production. Further developments in reaction theory and higher precision data are required before the validity of any such links can be assessed.

Lin Tang, Hui-Yu, Minghui Ding, & C.D. Roberts, Eur Phys J C **86**, 264 (2026)





- Good description of data is mainly provided by explicit implementation of *upper quark loop*.
- Of course, there is NO reason for ***Pomeron*** dominance near thr.
- There is **no fit** to diff. & total Xsec & predictions are really good.



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Experiment

CLAS
GlueX
007 J/ψ
CLAS
CENTER for NUCLEAR FEMTOGRAPHY

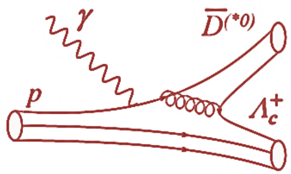
Deciphering Mechanism of Near-Threshold J/ψ Photoproduction

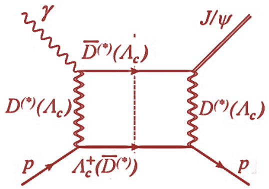
UNIVERSITÄT BONN

Meng-Lin Du, V. Baru, Feng-Kun Guo, Ch. Hanhart, U.-G. Meissner, A. Nefediev, & IIS, Eur Phys J C **80**, 1053 (**2020**)

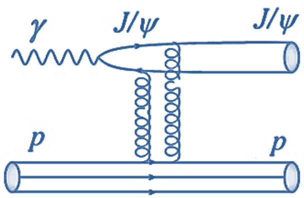
- It was shown that *fluctuation* of *photon* into ***open charm*** $\gamma p \to \Lambda_c \bar{D}$. is preferable than into *hidden charm* J/ψ.

K. Boreskov, A. Capella, A. Kaidalov, & J. Tran Than Van, Phys Rev D **47**, 919 (**1993**)





- $\bar{c}c$ *pair* is produced by ***1g*** & interacts with *proton*.



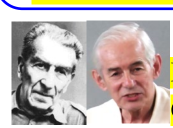
- $\bar{c}c$ *pair* is produced by ***photon*** via *VMD* & interacts with *proton* through ***2g*** exchange.

- Coupled-channel mechanism with ***VMD***

$$\left|a^{J=1/2}\right| = 0.2\ldots3.1 \text{ mfm}$$
$$\left|a^{J=3/2}\right| = 0.2\ldots3.0 \text{ mfm}$$

- These ***two*** *mechanisms* act simultaneously. Assuming there is only ***first*** one, then key consequence: *threshold cusps* **!**
- There is no fit to GlueX data.

- One **should study** *two-component* problem accounting for *interference* between these *two components*.
- Effect of *charm* exchange is smaller than *gluon* exchange.
- *Gluon* contribution can be strongly *suppressed* due to "*young*" effect.



E.L. Feinberg, Sov Phys Usp, **23**, 629 (**1980**)
Courtesy of Misha Ryskin, July **2020**

NSTAR 2026

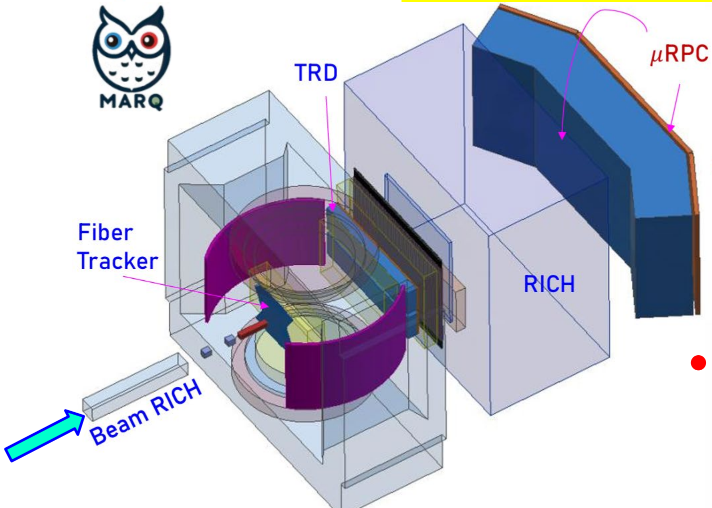
J-PARC for J/ψ & ϕ Production at Threshold

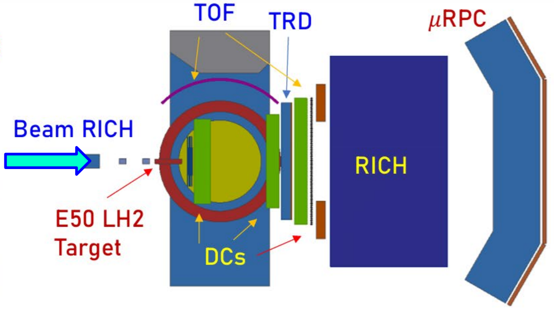
J-PARC for $\pi^- p \to J/\psi\, n \to (\ell^+\ell^-)\, n$

S.Y. Ryu *et al*. Proposal **P111** for J-PARC (**2024**)

- New high-energy π20/K10 beamline, utilized by P111 experiment

Spectrometer (MARQ & Dilepton Det)





- Two additional detectors will be added to the E50 spectrometer, which are the μRPC and the TRD (transition radiation detector).
- For detection of the $J/\psi \to e^+e^-$ decay, we also consider alternative detector candidates such as a large array of the forward EM calorimeter and/or preshower sampling calorimeters in the magnet.

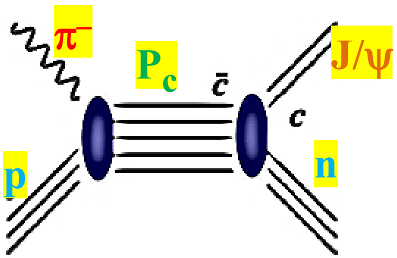
12

- Theoretical predictions for **J/ψ** production Xsec span wide range, from **1 pb** to **50 nb**, depending on interpretations of these limits.
- If Xsec reaches approximately 4 nb @ p = 9.5 GeV/c, Anticipated **J/ψ** yield in momentum range p = 8.2 − 11.0 GeV/c is estimated to be 10^4 events.

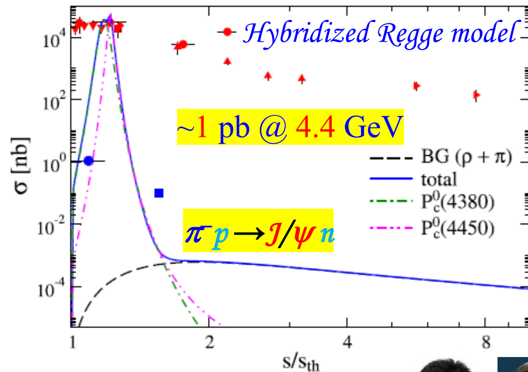
Courtesy of Sun Young Ryu, **September 2025**

- Key distinction of $\pi^- p \to J/\psi n$ reaction @ J-PARC is that, unlike photon-induced reactions - where photon creates quark pair @ interaction point, as seen in GlueX, $007^{J/\psi}$, & clas –pion-induced process involves *two quarks* that are already separated from beginning.
- We would add, however, that in **s**-channel resonance, $\bar{c}c$ separation may be different from that in **J/ψ** photoproduction.

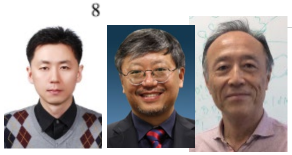
Theory for J/ψ Production using Pion Beam @ J-PARC

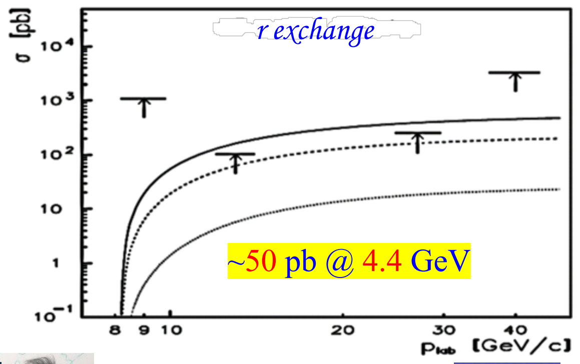


- Looking for bumps via ***constructive interference*** between **s**-channel P_c Res & non-resonant background.

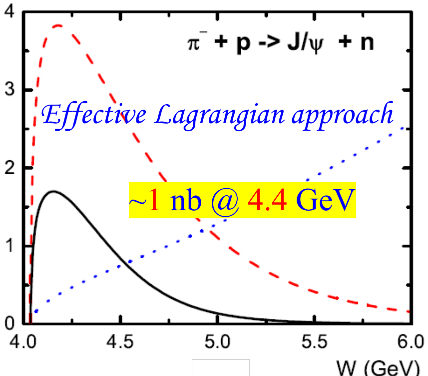


S.H. Kim, H.C. Kim, & A. Hosaka,
Phys Lett B **763**, 358 (**2016**)

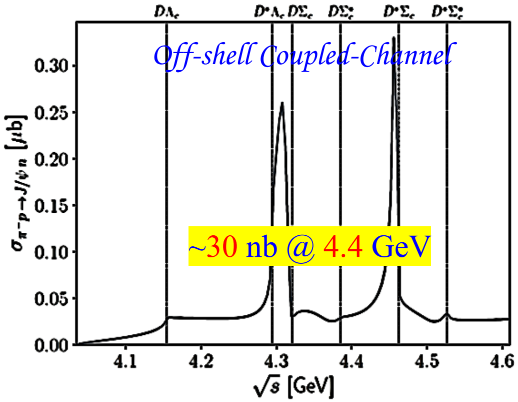




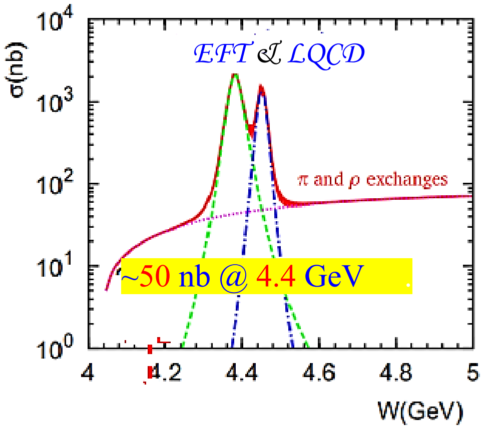
A. Sibirtsev & K. Tsushima,
arXiv:nucl-th\9810029



J.J. Wu & T.S.H. Lee,
Phys Rev C **88**, 015205 (**2013**)



S. Clymton, S.Y. Ryu, J.K. Ahn, &
H.C. Kim, arXiv:**2605**.28285 [hep-ph]

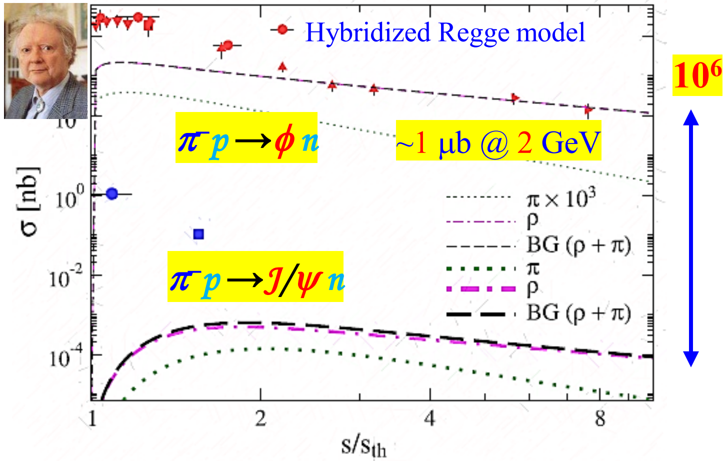


Q.F. Lue, X.Y. Wang, J.J. Xie, X.R. Chen, &
Y.B. Dong, Phys Rev D **93**, 034009 (**2016**)

J-PARC for $\pi^- p \to (K^+K^-)\, n \to \phi\, n$

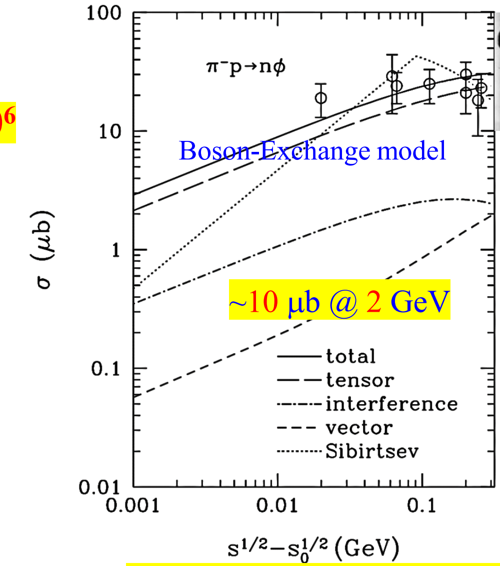
E95 Proposal, J-PARC, 2024

No thr data

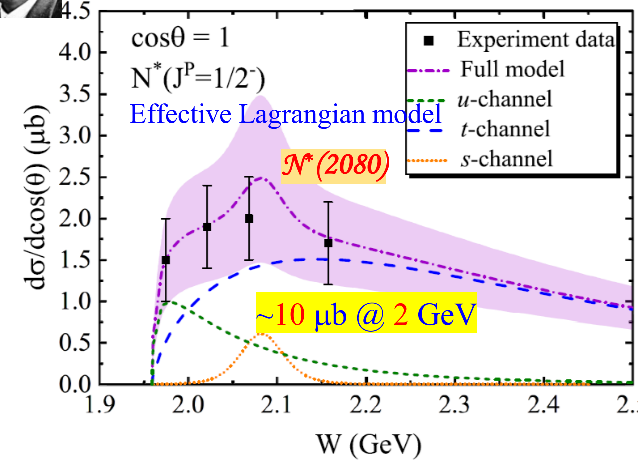


10^6

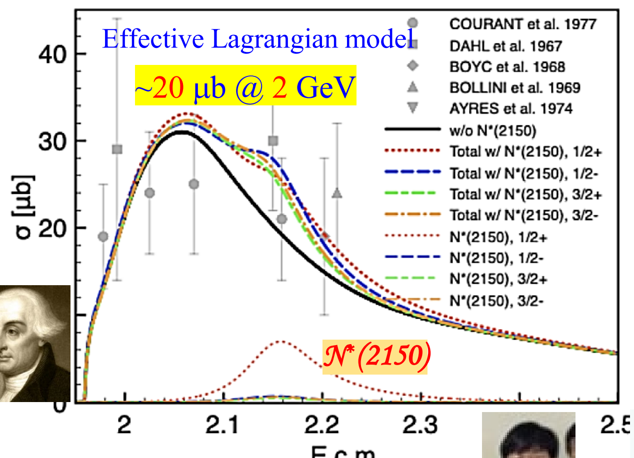
S.H. Kim, H.C. Kim, & A. Hosaka, Phys Lett B **763**, 358 (2016)



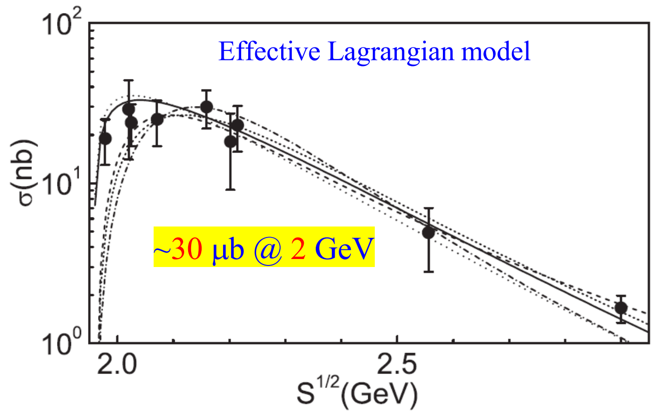
X.Y. Wang, H.F. Zhou, & X. Liu, Phys Rev D **110**, 014026 (2024).



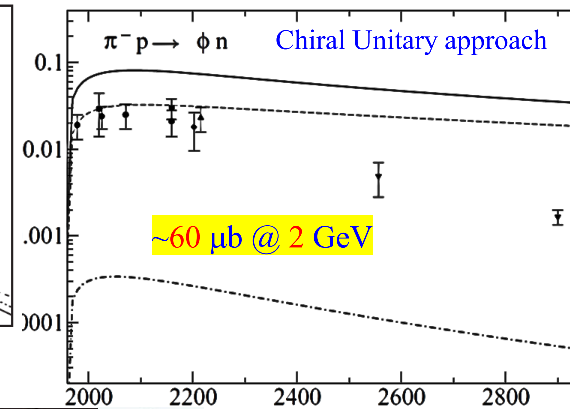
W.S. Chung, G.Q. Li, & C.M. Ko, Phys Lett B **401**, 1 (1997)



D. Lee, S.-Nam, & J. K. Ahn, New Phys: Sae Mulli, **76**, 119 (2026)



J.J. Xie, B.S. Zou, & H.C. Chiang, Phys Rev C **77**, 015206 (2008).

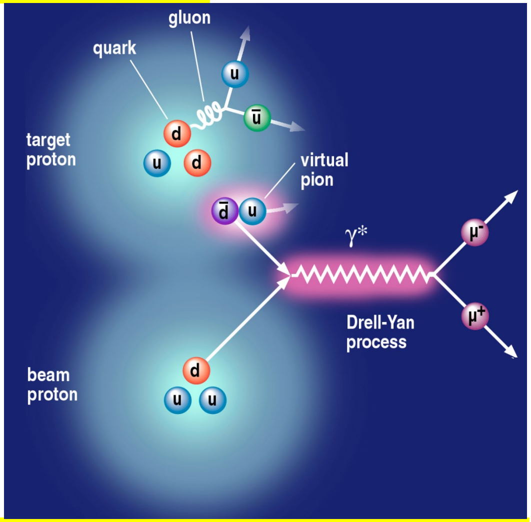


M. Doering, E. Oset, & B.S. Zou, Phys Rev C **78**, 025207 (2008)

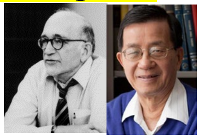
Polarization of Quarkonium

J-PARC for $\pi^- p \to J/\psi\, n \to (e^+e^-)\, n$

- Crucial point for **$\pi^- p \to V n$** case (as J-PARC will be measured) is that *photon* creates/produces quark pair @ POINT (@ GlueX) while in *pion* case, we deal with two quarks separated from one another @ beginning.



- Depending on production mechanism for ***J/ψ***, polarization of ***J/ψ*** could change. For example, some production mechanisms are expected to produce largely unpolarized ***J/ψ*** (such as inclusive production), while other mechanisms can produce polarized ***J/ψ*** (such as exclusive production or thr production). For example, when ***NuSea*** Collaboration measured polarization of ***J/ψ*** produced in *pA* inclusive production @ 800 GeV beam energy, they found that *J/ψ* is somewhat polarized, but much less polarized than *Drell-Yan* di-leptons.



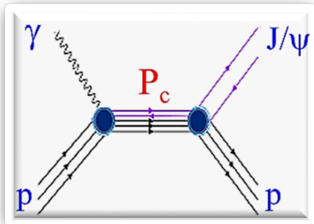
C.N. Brown *et al*. Phys Rev Lett **86**, 2529 (**2001**)
T.H. Chang *et al*. Phys Rev Lett **91**, 211801 (**2003**)

Jen-Chieh Peng: ``*Polarization of quarkonium remains mystery*''.

J/ψ polarization matrix is measured via angular distribution of electrons in $J/\psi \to e^+e^-$ decay.

NSTAR 2026

Plausibility of Heavy 5q in GlueX Data

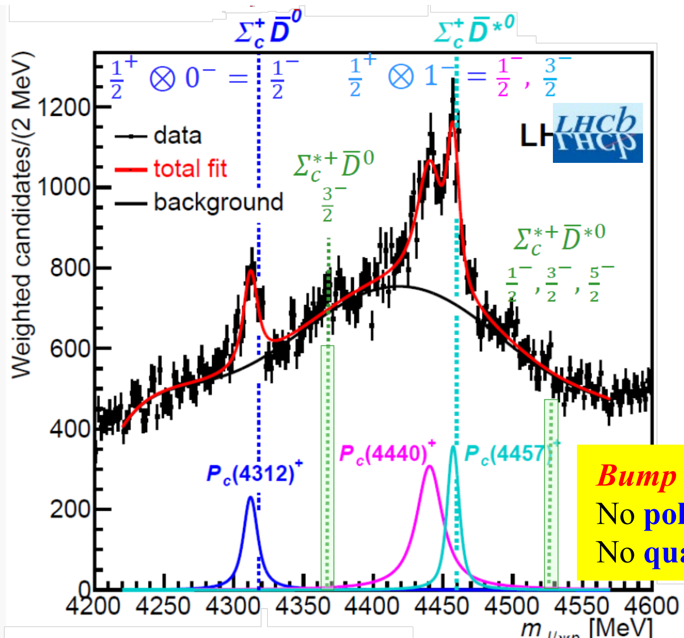


LHCb for *Narrow Pentaquarks* from $\Lambda_b \to J/\psi p K^-$

R. Aaij *et al*, Phys Rev Lett **122**, 222001 (**2019**)

GlueX *Upper Limit* from $\gamma p \to J/\psi p \to (e^+e^-)p$ @ *Threshold*

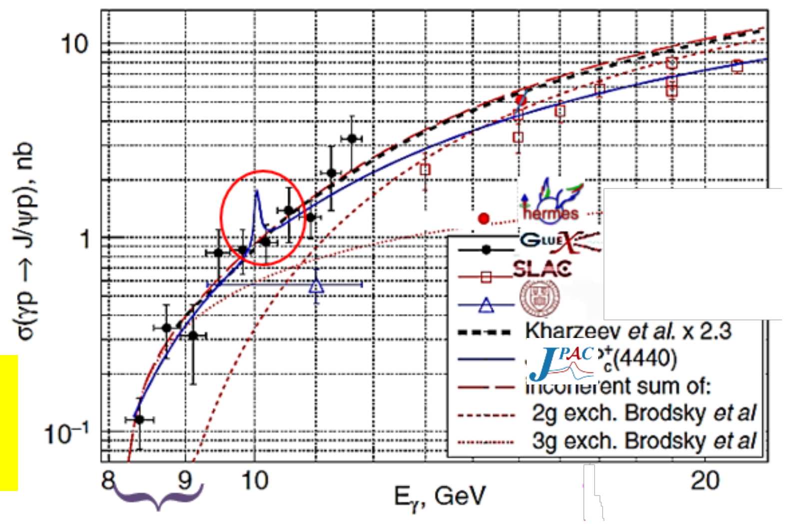
A. Ali *et al*, Phys Rev Lett **123**, 072001 (**2019**)



Bump hunting while there are
No **pole position**
No **quantum numbers**

State	M (GeV)	Γ[$P_c \to J/\psi p$] (MeV)	BR	Significance
$P_c(4312)^+$	$4311.9 \pm 0.7^{+6.8}_{-0.6}$	$9.8 \pm 2.7^{+3.7}_{-4.5}$	$0.3 \pm 0.07^{+0.34}_{-0.09}$	7.3σ
$P_c(4440)^+$	$4440.3 \pm 1.3^{+4.1}_{-4.7}$	$20.6 \pm 4.9^{+8.7}_{-10.1}$	$1.1 \pm 0.33^{+0.22}_{-0.10}$	5.4σ
$P_c(4457)^+$	$4457.3 \pm 0.6^{+4.1}_{-1.7}$	$6.4 \pm 2.0^{+5.7}_{-1.9}$	$0.53 \pm 0.16^{+0.15}_{-0.13}$	5.4σ

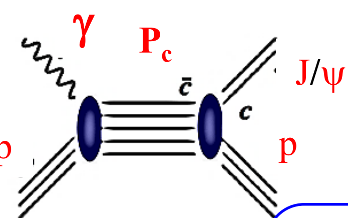
(2016 – 2017 data: 469±22 $J/\psi \to e^+e^-$)






- GlueX *sees no evidence for* LHCb P_cs
  *Upper limits @ **90%** CL*

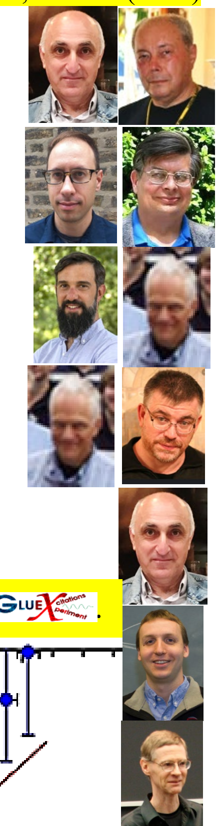
State	Upper Limit (%)
$P_c(4312)$	4.6
$P_c(4440)$	2.3
$P_c(4457)$	3.8



Alternative Solution for GlueX Data

S. Adhikari *et al*, Phys Rev C **108**, 025201 (**2023**)

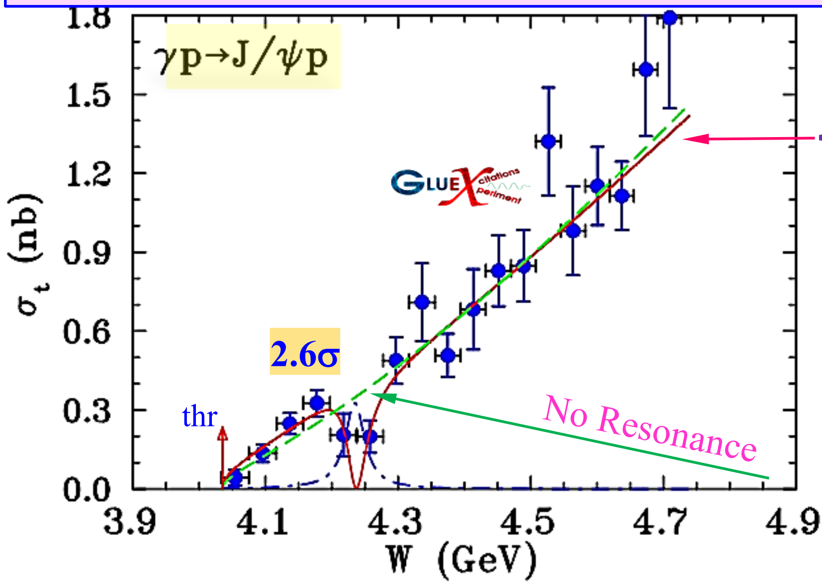
IIS, W.J. Briscoe, E. Chudakov, I. Larin, L. Pentchev, A. Schmidt, & R.L. Workman, Phys Rev C **108**, 015202 (**2023**)



- We suggested to apply *rearrangement interference* for revealing *faint* resonance signals (***amplification*** by *interference* with *strong* background signal).
- Relative *phase* α leads to *constructive* (***bump***) or *destructive* (***dip***) *interference* for particular **PW**.

$$f = b + R \cdot \exp(2i\alpha)$$

2016–2018 data: **2270**±58 $\gamma p \to J/\psi p \to e^+e^- p$ & **320** pb^{-1}



Resonance: χ^2/ndf=11.99/12=**1.00**

M= 4235 ±8 MeV

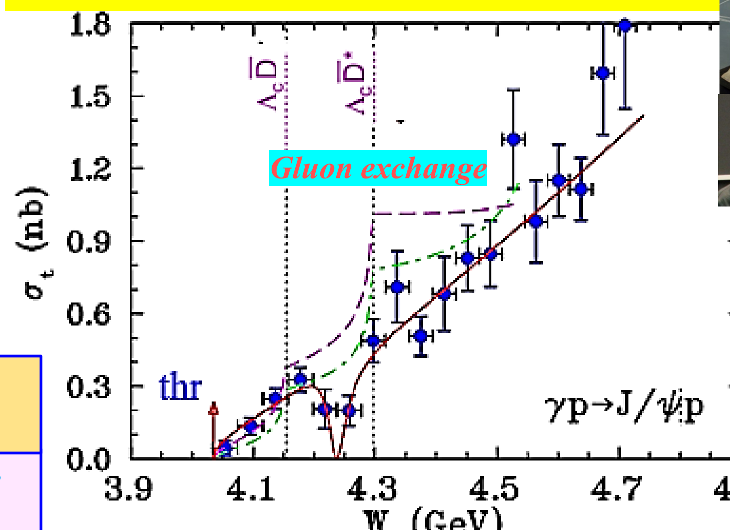
Γ= 35.4±8.2 MeV

X= 0.023±0.005

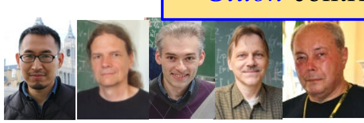
α= 40.8±5.7 deg

Resolution **~6** MeV

- *Cusp* effect is visible & in agreement with GlueX.



- Effect of *charm* exchange is smaller than *gluon* exchange.
- *Gluon* contribution can be strongly *suppressed* due to "*young*" effect.



- Interference between *open charm* & ***gluon exchange*** may produce *dip*, but there is room for *resonance*.

Meng-Lin Du, V. Baru, Feng-Kun Guo, Ch. Hanhart, U.-G. Meissner, A. Nefediev, & IIS, Eur Phys J C **80**, 1053 (**2020**)

Summary

- “*Young*” **V** hypothesis may explain fact that obtained SL value for ϕ-p, compared to typical hadron size of 1 fm, indicates that proton is more transparent for ϕ-meson compared to ω-meson & is much more transparent for **J**/ψ-meson.

$|\alpha_{\Upsilon p}| << |\alpha_{J/\psi p}| << |\alpha_{\phi p}| << |\alpha_{\omega p}|$

- Furthermore, ***pQCD*** predictions support phenomenological determination of heavy vector meson-nucleon scattering lengths.

- J-PARC is able to measure $\pi^- p \to \phi\, n$ E95 & $\pi^- p \to J/\psi\, n$ P111 @ thresholds, which are free from VMD, which is important input to phenomenology (PWA).

- Upcoming J-PARC threshold measurements of reaction $\pi^- p \to J/\psi\, n \to (l^+ l^-) n$ will help to evaluate possible role of heavy pentaquark, **P_c**, states in low-energy ***J/ψ*** production & effects caused by nucleon **FF**s.

- @ thr, proton FF should reveal itself.
However, if process goes via some resonance/pentaquark, there slightly different FF.

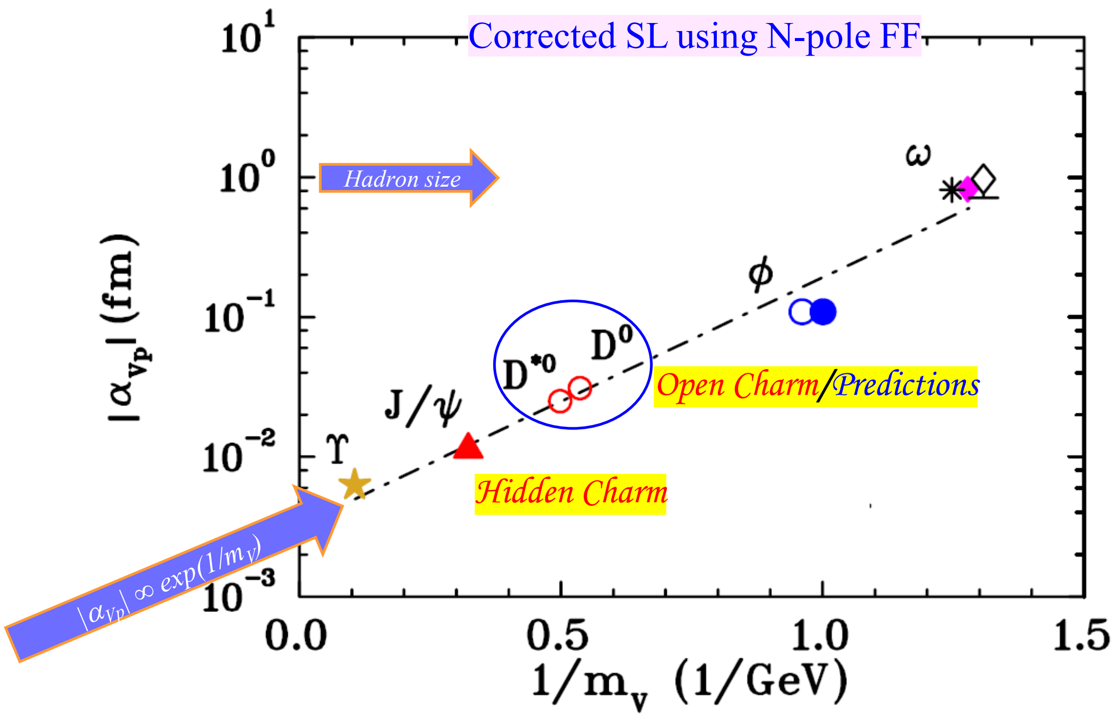
- Jefferson Lab further studies on both *nucleons* & ***nuclei*** SRC in *heavy* **V** photo- & ***electro-production*** RGA & RGK will significantly extend our knowledge of *gluonic* structure of nuclear matter.

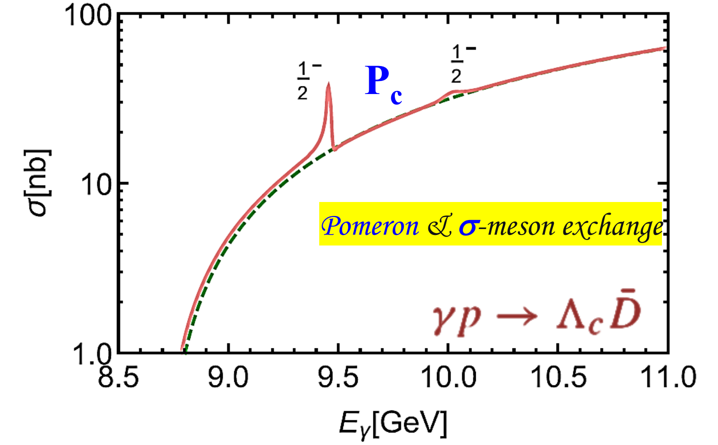
- & ability allows us to understand dynamics of $\bar{s}s$ & $\bar{c}c$ & $b\bar{b}$ production @ threshold.

- *Polarized measurements* are important contribution to model-independent **PWA**.

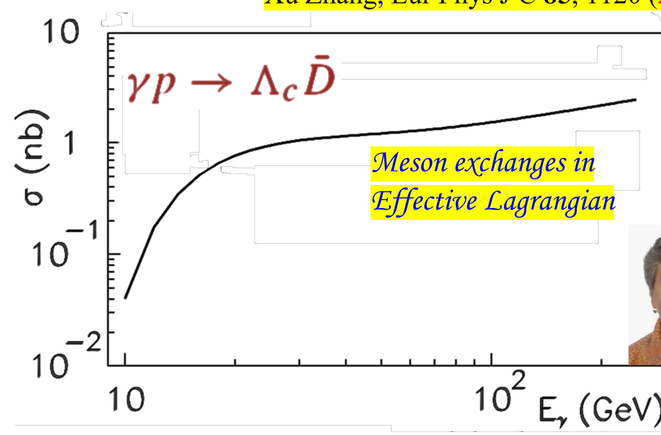
$\gamma p \rightarrow \Lambda_c \bar{D}$ & $\pi^- p \rightarrow \Lambda_c D^-$

- No ***Open Charm*** threshold data.
- One can predict **SL** using Phenomenology.





Xu Zhang, Eur Phys J C **85**, 1120 (**2025**)



E. Tomasi-Gustafsson [arXiv:hep-ph/**0411295**[hep-ph]

- Problem is "*young effect*". **SL** depends on **Q**-**Q** separation.
- In the case of ***Open Charm***, this separation is driven just by $\mathbf{m_Q}$, while in **V** photoprod it is somewhere between **Vs** size (which is larger than $\mathbf{1/m_Q}$) & $\mathbf{1/m_Q}$.
- That is, we expect ***Open Charm*** **SL** to be smaller than **prediction** coming from this curve (one can consider this prediction as upper limit).

- Theory is blind @ thr; most couplings are unknown.
- Just exp data will allow us to understand $c\bar{u}$ & qqq interaction dynamics.

Backup

Vector Meson Threshold Photoproduction with Phenomenology

PHYSICAL REVIEW C 91, 045207 2015

Photoproduction of the ω meson on the proton near threshold

A2

I. I. Strakovsky,[1,*] S. Prakhov,[1,2,3,†] Ya. I. Azimov,[4] P. Aguar-Bartolomé,[2] J. R. M. Annand,[5] H. J. Arends,[2] K. Bantawa,[6] R. Beck,[7] V. Bekrenev,[4] H. Berghäuser,[8] A. Braghieri,[9] W. J. Briscoe,[1] J. Brudvik,[3] S. Cherepnya,[10] R. F. B. Codling,[5] C. Collicott,[11,12] S. Costanza,[9] B. T. Demissie,[1] E. J. Downie,[1,2] P. Drexler,[8] L. V. Fil'kov,[10] D. I. Glazier,[5,13] R. Gregor,[8] D. J. Hamilton,[5] E. Heid,[1,2] D. Hornidge,[14] I. Jaegle,[15] O. Jahn,[2] T. C. Jude,[13] V. L. Kashevarov,[2,10] I. Keshelashvili,[15] R. Kondratiev,[16] M. Korolija,[17] M. Kotulla,[8] A. Koulbardis,[4] S. Kruglov,[4,‡] B. Krusche,[15] V. Lisin,[10] K. Livingston,[5] I. J. D. MacGregor,[5] Y. Maghrbi,[15] D. M. Manley,[6] Z. Marinides,[1] J. C. McGeorge,[5] E. F. McNicoll,[5] D. Mekterovic,[17] V. Metag,[8] D. G. Middleton,[2,14] A. Mushkarenkov,[9] B. M. K. Nefkens,[3,‡] A. Nikolaev,[7] R. Novotny,[8] H. Ortega,[2] M. Ostrick,[2] P. B. Otte,[2] B. Oussena,[1,2] P. Pedroni,[9] F. Pheron,[15] A. Polonski,[16] J. Robinson,[5] G. Rosner,[5] T. Rostomyan,[15] S. Schumann,[2] M. H. Sikora,[1,3] A. Starostin,[3] I. Supek,[17] M. F. Taragin,[1] C. M. Tarbert,[13] M. Thiel,[8] A. Thomas,[2] M. Unverzagt,[2,7] D. P. Watts,[13] D. Werthmüller,[15] and F. Zehr[15]
(A2 Collaboration at MAMI)

PHYSICAL REVIEW C 101, 042201(R) (2020)

$J/\psi\, p$ scattering length from GlueX threshold measurements

Igor I. Strakovsky,[1,*] Denis Epifanov,[2,3] and Lubomir Pentchev[4]

PHYSICAL REVIEW C 101, 045201 (2020)

Comparative analysis of ωp, ϕp, and $J/\psi p$ scattering lengths from A2, CLAS, and GlueX threshold measurements

Igor I. Strakovsky,[1,*] Lubomir Pentchev,[2] and Alexander I. Titov[3]

PHYSICAL REVIEW D 104, 074028 (2021)

Threshold Upsilon-meson photoproduction at the EIC and EicC

Igor I. Strakovsky,[1,*] William J. Briscoe,[1] Lubomir Pentchev,[2] and Axel Schmidt[1]

CENTER for NUCLEAR FEMTOGRAPHY

PHYSICAL REVIEW C 108, 015202 2023

Plausibility of the LHCb $P_c(4312)^+$ in the GlueX $\gamma p \to J/\psi p$ total cross sections

Igor Strakovsky,[1,*] William J. Briscoe,[1] Eugene Chudakov,[2] Ilya Larin,[3,4] Lubomir Pentchev,[2] Axel Schmidt,[1] and Ronald L. Workman[1]

PHYSICAL REVIEW D 112, 114045 2025

ρ-meson nucleon scattering length from CLAS threshold photoproduction measurements

Igor I. Strakovsky,[1,*] Evgeny L. Isupov,[2,†] Victor Mokeev,[3,‡] and Axel Schmidt[1]

PHYSICAL REVIEW C 113, 065201 (2026)

J/ψ-meson–nucleon scattering length from threshold photoproduction on light nuclei

Igor I. Strakovsky,[1,*] William J. Briscoe,[1] Philipp Gubler,[2] Jackson R. Pybus,[3] Axel Schmidt,[1] and Alexander Somov[4]

Jefferson Lab

PHYSICAL REVIEW D 113, 114023 (2026)

JLab and J-PARC measurements for J/ψ production at threshold

Igor I. Strakovsky[*] and William J. Briscoe[†]

Jung Keun Ahn[‡] Misha G. Ryskin[§] Axel Schmidt[‖]

Jefferson Lab

J-PARC

Total Cross Sections for Vector Meson Photoproduction off Proton

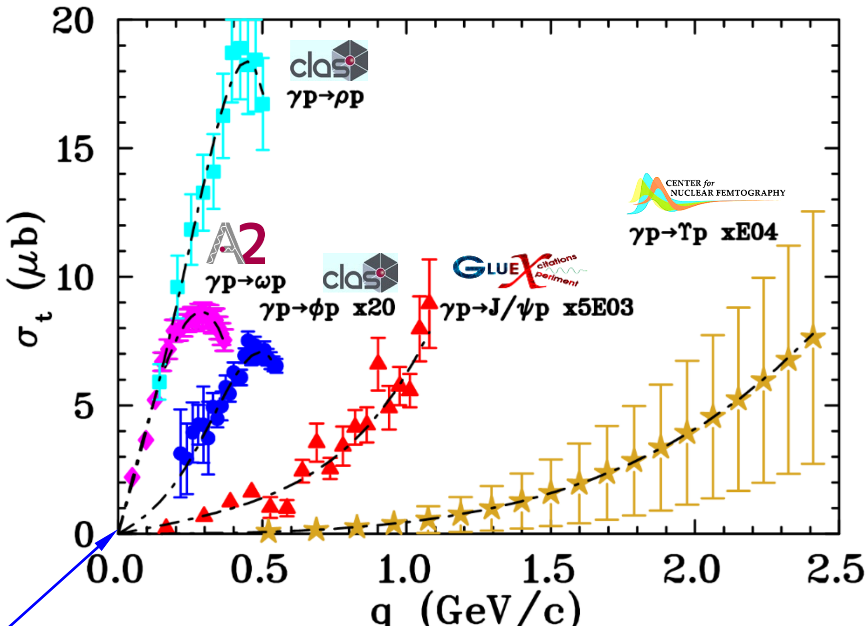
- Traditionally, σ_t behavior of near-threshold binary *inelastic* reaction

$$m_a + M_b < m_c + M_d$$

is described as series of *odd* powers in q (*even* powers in case of *elastic*).

$$\boxed{\sigma_t = a\, q + b\, q^3 + c\, q^5}$$

- ***Linear*** term is determined by two independent ***S***-waves only with total spin *1/2* &/or *3/2*.
- Contributions to ***cubic*** term come from both ***P***-wave amplitudes & ***W*** dependence of ***S***-wave amplitudes,
- ***Fifth***-order term arises from ***D***-waves & ***W*** dependencies of ***S***- & ***P***-waves.



- Our ***assumption*** is that there are no *VN* ***bound states*** below experimental q_{min}.

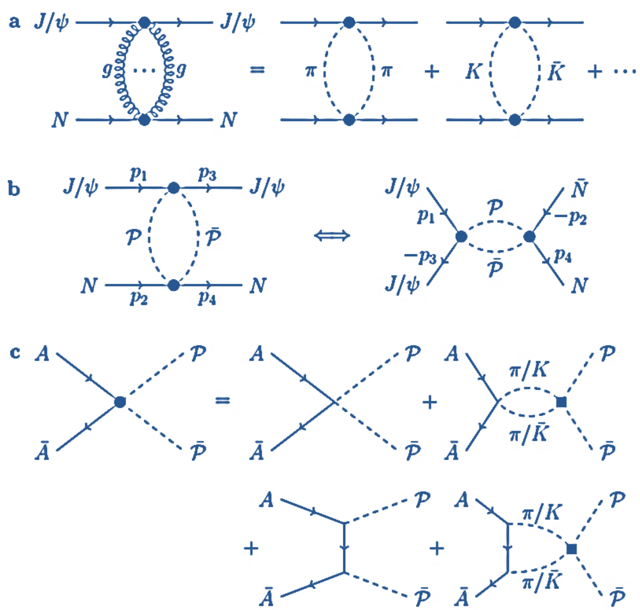
ω	A2	**a** = (**4.42**±0.14) x 10^{-2} μb/(MeV/c) IIS, S. Prakhov, Ya. Azimov *et al*, Phys Rev C **91**, 045207 (**2015**)
ρ^0	clas	**a** = (**3.99**±0.52) x 10^{-2} mb/(MeV/c) IIS, V. Mokeev, E. Isupov, A. Schmidt, Phys Rev D **112**, 114045 (**2025**)
ϕ	clas	**a** = (**0.34**±0.12) x 10^{-3} μb/(MeV/c) IIS, L. Pentchev, & A.I. Titov, Phys Rev C **101**, 045201 (**2020**)
J/ψ	GlueX	**a** = (**0.43**±0.12) x 10^{-6} μb/(MeV/c) IIS, D. Epifanov, & L. Pentchev, Phys Rev C **101**, 042201 (**2020**)
Υ	CENTER for NUCLEAR FEMTOGRAPHY	**a** = (**0.37**±0.04) x 10^{-9} μb/(MeV/c) IIS, W.J. Briscoe, L. Pentchev, & A. Schmidt, Phys Rev C **104**, 074028 (**2021**)

- Dramatic differences in hadronic factors $\boxed{h^2 = a}$, as slopes (***a***) of σ_t @ threshold as function of q varies significantly from ω to ϕ to J/ψ to Y.

- Therefore, such big difference in *SL* is determined mainly by *hadronic* factor *h*.

Deciphering Mechanism of Near-Threshold J/ψ Photoproduction

Bing Wu, Xiang-Kun Dong , Meng-Lin Du, Feng-Kun Guo , & Bing-Song Zou, Fund Res **5**, 2530 (2025)



Soft-gluon exchange between **J/ψ** & N

Crossing symmetry between **J/ψN** scattering & $J/\psi J/\psi \to N\bar{N}$

$A\bar{A} \to \mathcal{P}\bar{\mathcal{P}}\,(A = N, J/\psi,$ and $\mathcal{P} = \pi, K)$

- Scattering can happen through **two** distinct mechanisms:

  coupled-channel mechanism via *open-charm* meson-baryon intermediate states,

  $\boxed{a_{J/\psi N} \in [-10, -0.1] \times 10^{-3}\ \text{fm}}$

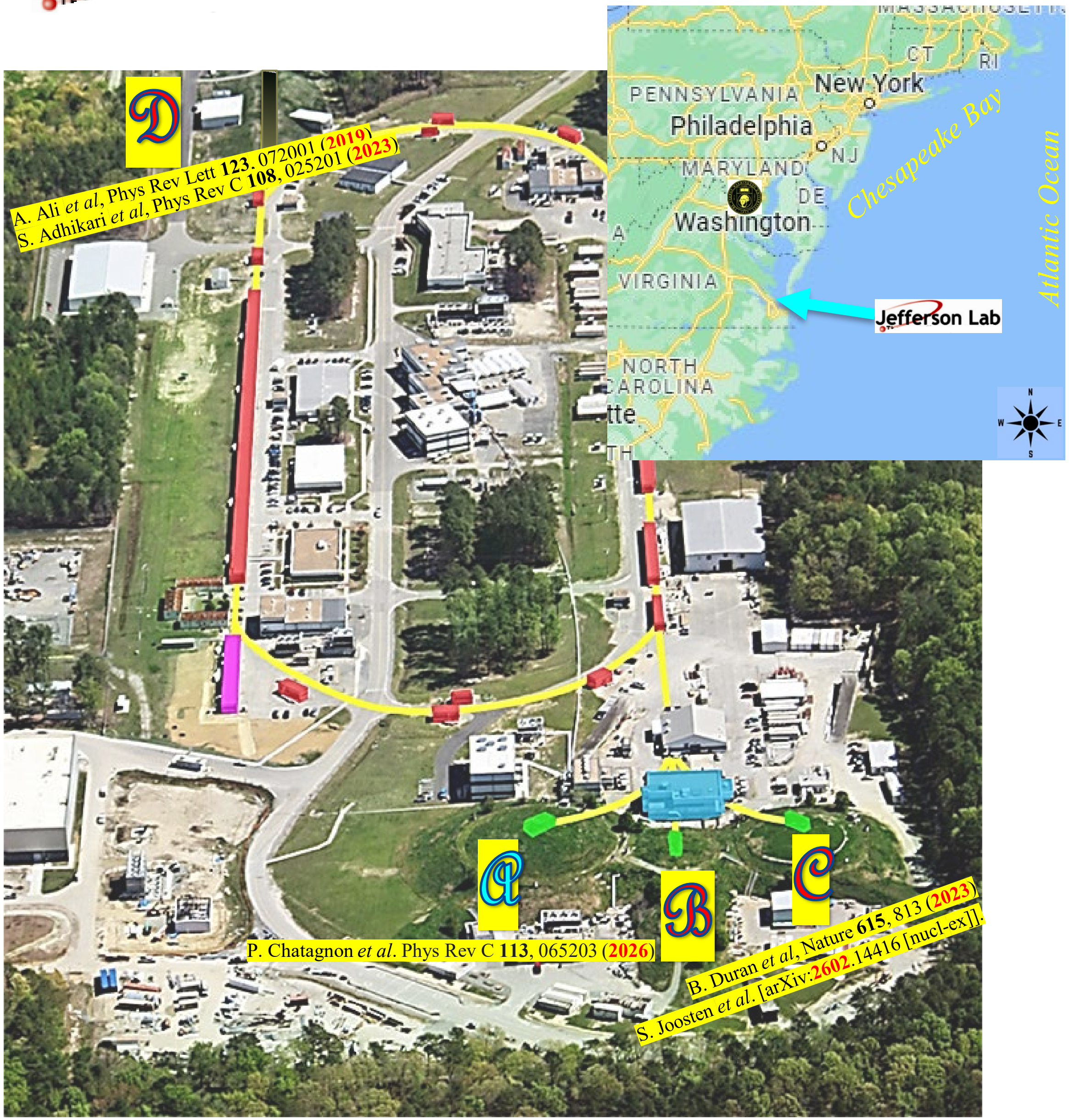
  soft-gluon exchange mechanism - Authors said - this mechanism is dominant.

  $\boxed{a_{J/\psi N} \lesssim -0.16\ \text{fm}}$

- They still get *SL* larger than that from GlueX.
- They account only for *pion* & *kaon* in **t**-channel neglecting heavier contribution (that is final *SL* may be bit larger).

JLab for Threshold J/ψ Photoproduction on Proton

Jefferson Lab *Continuous Electron Beam Accelerator Facility in 2026*



1995 — 2012…

Energy 0.4 — 6.0 GeV

- 200 μA, *Polarization* 85%
- Simultaneous delivery 3 Halls — 𝔄, 𝔅, ℭ

- 500+ PhDs completed
- On average 22 US Ph.Ds per year, roughly 25–30% of US Ph.Ds in nuclear physics
- 1530 users in FY16, ~1/3 international from 37 countries

…2016 — …

Energy 0.4 — 12.0 GeV

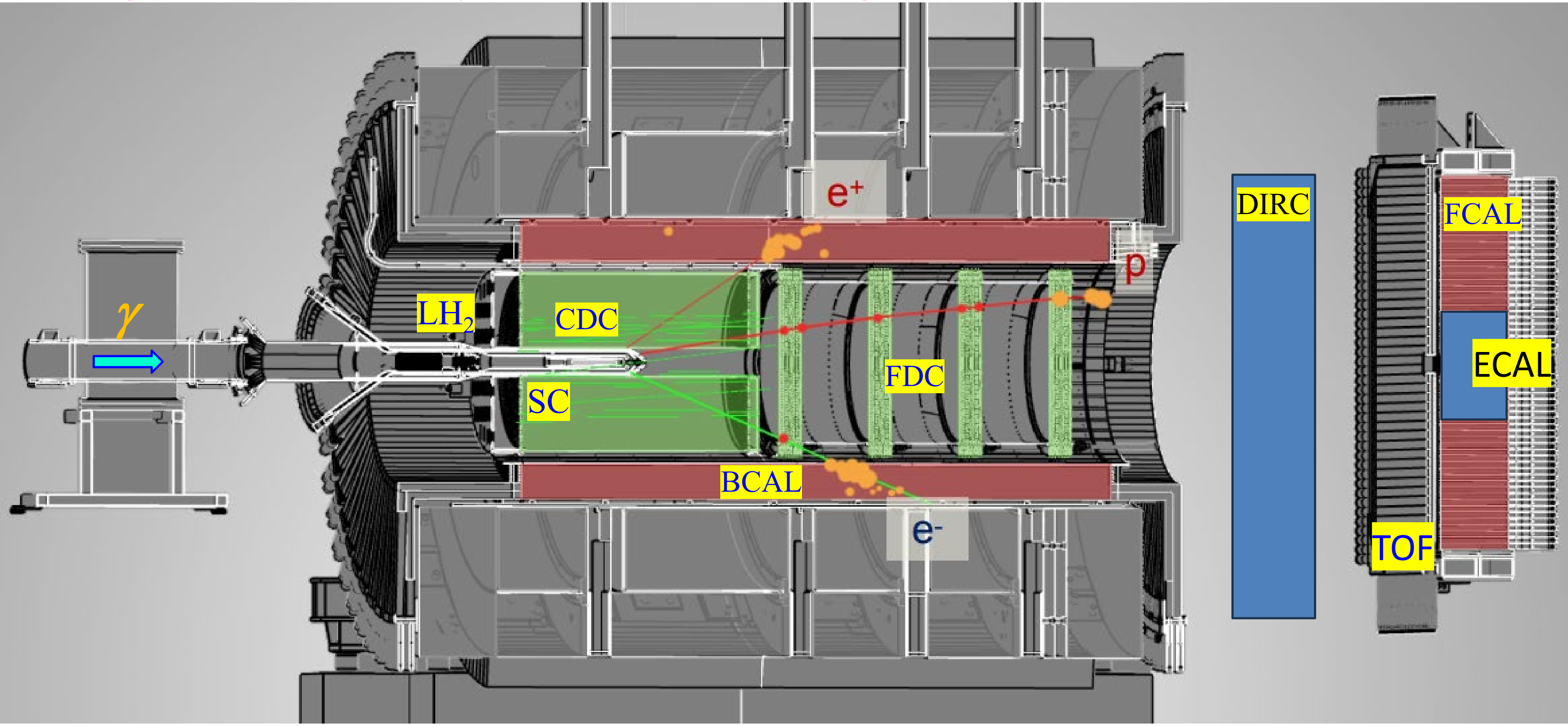
- 150 μA, *Polarization* 85%
- FY18: First simultaneous delivery to 4 Halls — 𝔄, 𝔅, ℭ, 𝔇

- Jefferson Lab with 12 GeV beam of e^-, has unique opportunity to measure high statistical J/ψ photoprod Xsec @ thr, which is 8.2 GeV.

Exclusive Reaction $\gamma p \to J/\psi p \to (e^+e^-)p$ with GlueX Detector

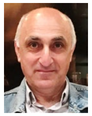
GlueX detector has full acceptance - direct measurement of *tot Xsec* - no need to extrapolate to low/high **t**

- 2T-solenoid, LH_2 target
- Tracking (FDC, CDC) , Calorimetry (BCAL, FCAL, ECAL), Timing (TOF, SC)



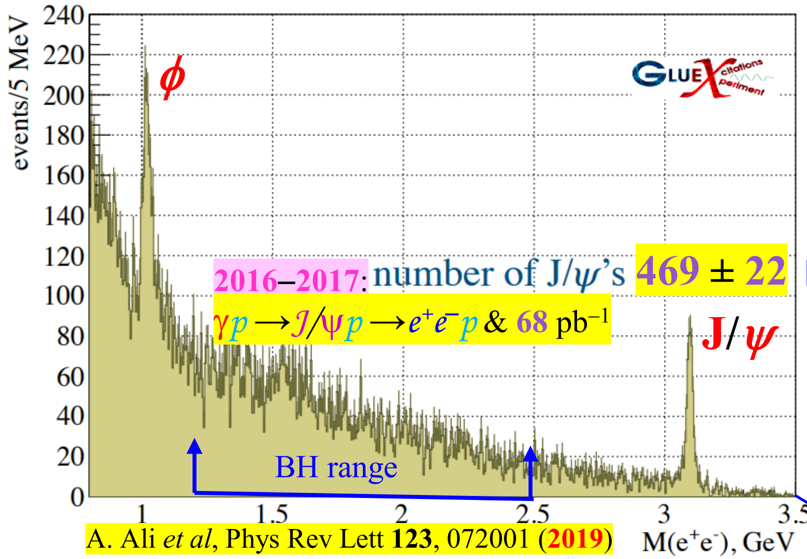
- Hermetic detector: 1^0–120^0 *polar* & full *azimuthal* acceptance.
- Intensity: (2–5) x10^7 γ/sec above J/ψ thr (8.2 GeV).
- Tracking: σ_p/p ~ 1–5 %.
- Calorimetry: $\sigma_E/E \sim 6\,\%/\sqrt{E} + 2\,\%$.
- e^- separated from π^- by E/p – energy deposition in calorimeters over measured momentum (π^- >10^3 times more than e^-).

Courtesy of Lubomir Penchev, **2024**

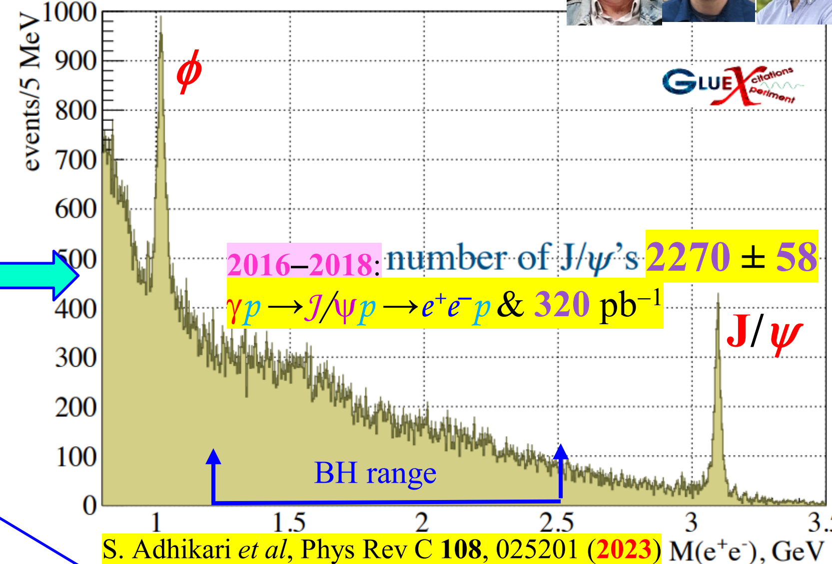


S. Adhikari *et al*, Nucl Inst Meth A **987**, 164807 (**2021**)

GlueX e^+e^- Invariant Mass Spectrum & Statistics

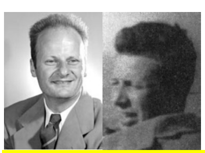


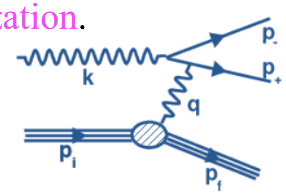
A. Ali *et al*, Phys Rev Lett **123**, 072001 (2019)



S. Adhikari *et al*, Phys Rev C **108**, 025201 (2023)

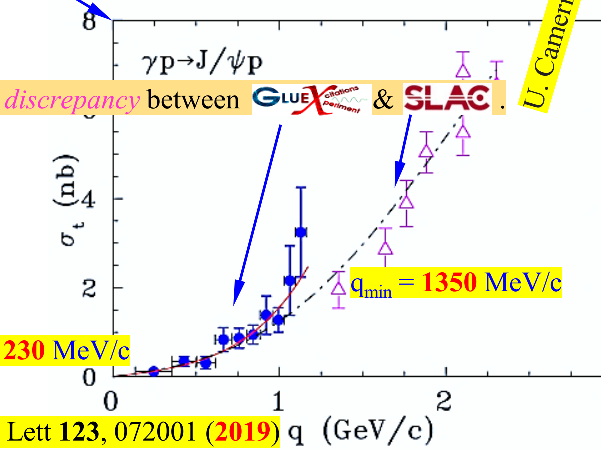
- Tagged photon beam (**0.2%** E_γ resolution) & exclusivity of reaction.
- Kinematic fit (constrained mostly by recoil proton): **13** MeV mass resolution; no radiative tail.
- J/ψ yields extracted from fits of **M(e$^+$e$^-$)** distributions.
- BH (**1.2–2.5** GeV) used for normalization.





H. Bethe & W. Heitler, Proc Royal Soc London. Ser A, **146**, 83 (1934)

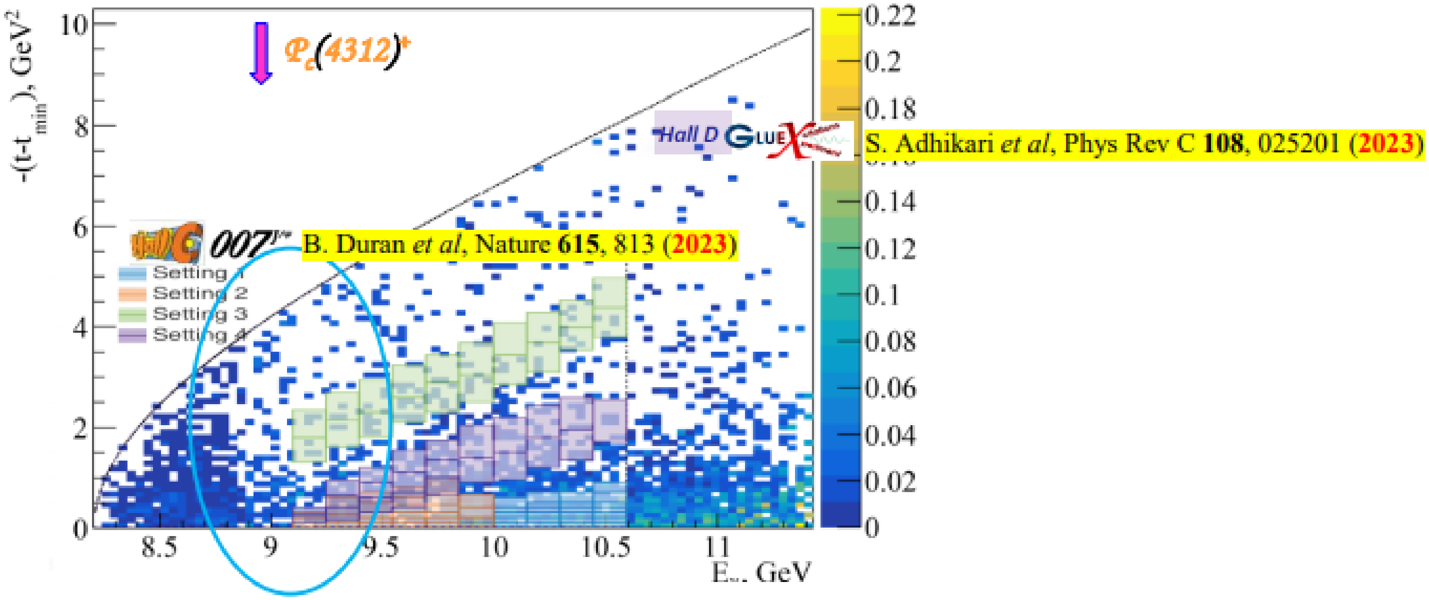
- There is ***no discrepancy*** between GlueX & SLAC.



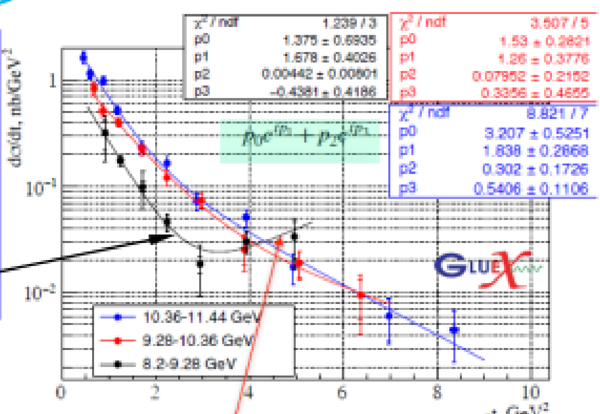
A. Ali *et al*, Phys Rev Lett **123**, 072001 (2019)

U. Camerini *et al*, Phys Rev Lett **35**, 483 (1975)

J/ψ Threshold Region Coverage



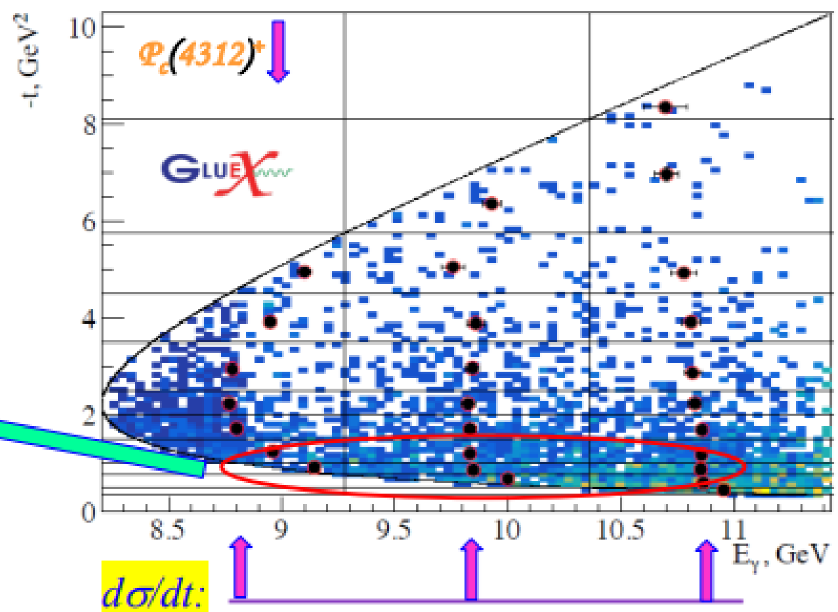
- Data is fitted with sum of two exponential functions.
- Second exponential contribution is most significant in lowest energy bin, where slope changes sign.



- Exponentially falling t-dependence

however:

- Enhancement of $d\sigma/dt$ at high t (for the lowest energy slice), indicates contribution beyond gluon exchange



$\gamma p \to J/\psi p \to (e^+e^-)p$ *Measurements from 007*$^{J/\psi}$
$\to (\mu^+\mu^-)p$

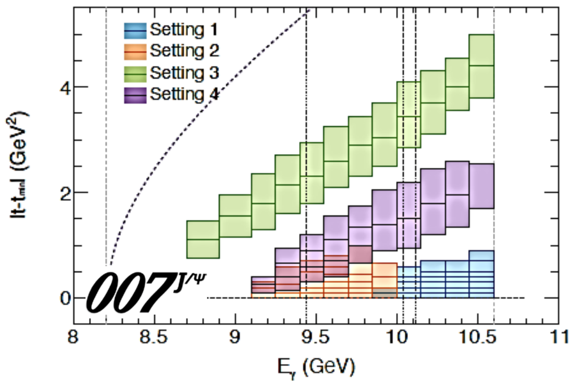
B. Duran *et al*, Nature **615**, 813 (2023)
S. Joosten *et al*, arXiv:2602.14416 [nucl-ex]

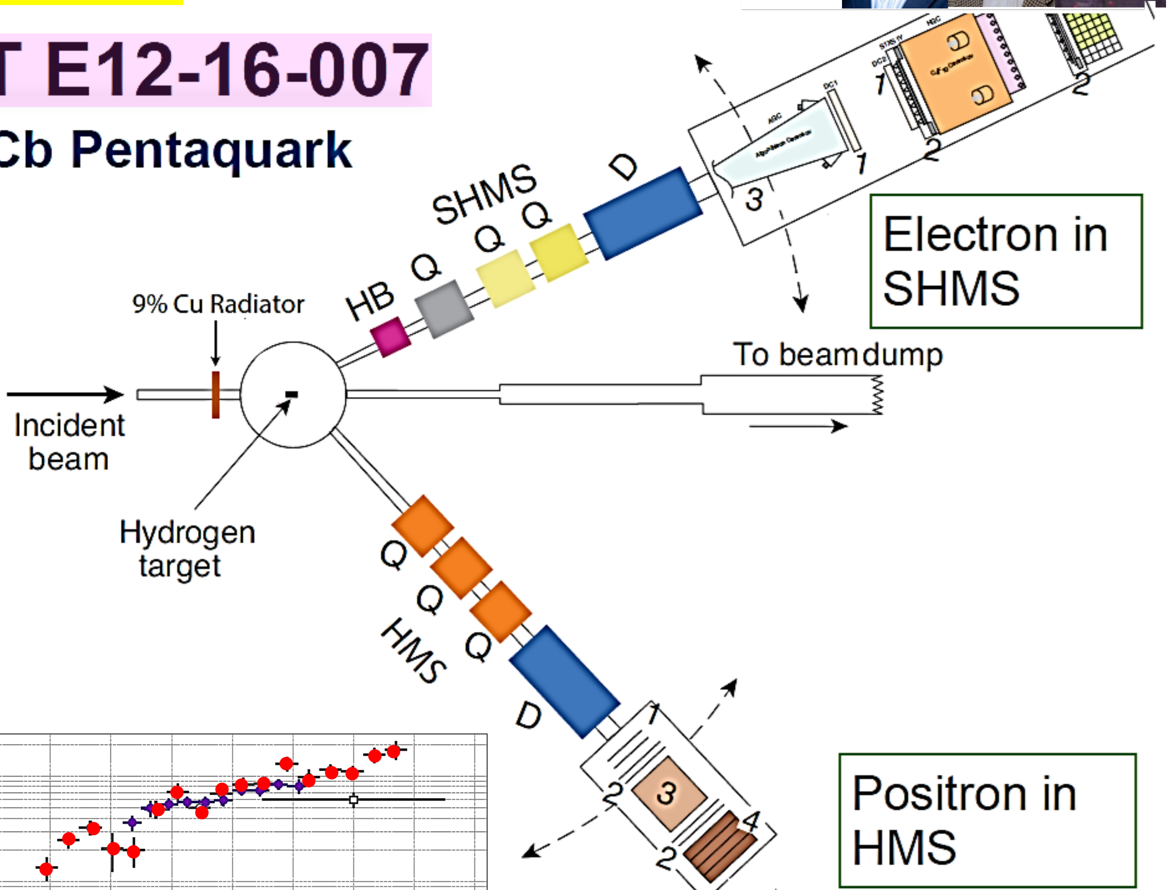
PDG $\Gamma(e^+e^-) = \Gamma(\mu^+\mu^-) = \mathbf{5.53}$ keV

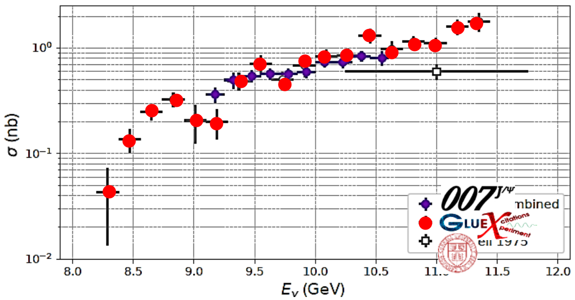
JLAB EXPERIMENT E12-16-007

J/ψ-007: Search for the LHCb Pentaquark

- Ran February 2019 for ~8 PAC days
- High intensity real photon beam (50μA electron beam on a 9% copper radiator)
- 10cm liquid hydrogen target
- Detect J/ψ decay leptons in coincidence
  - Bremsstrahlung photon energy fully constrained





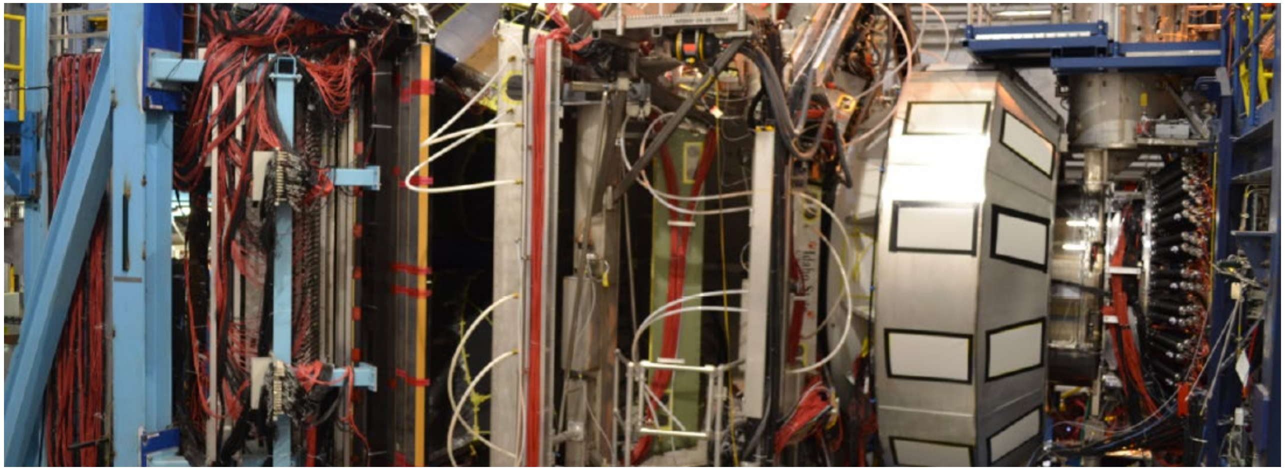


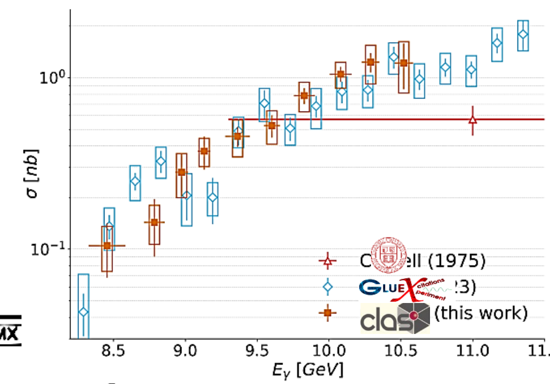
S. Ali *et al*, Inst Meth A **1083**, 171070 (2026)

Courtesy of Sylvester Joosten, July 2024

$\gamma^* p \rightarrow J/\psi p \rightarrow (e^+e^-)p$ Measurements from CLAS

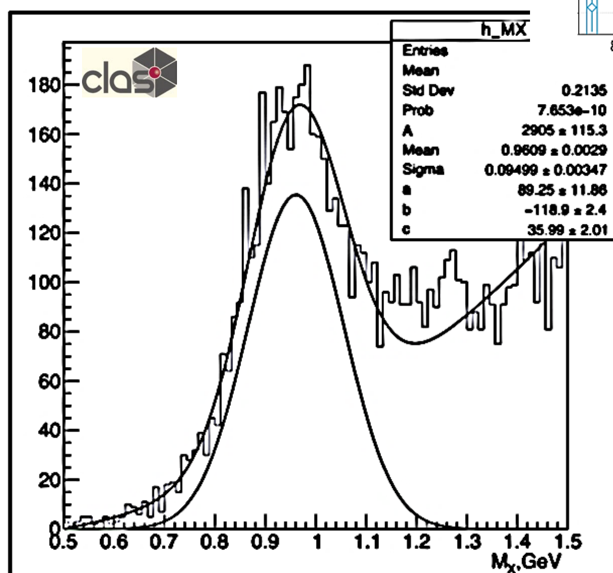
P. Chatagnon *et al.* Phys Rev C **113**, 065203 (**2026**)





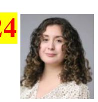
V.D. Burkert *et al*, Nucl Inst Meth A **959**, 163419 (**2020**).

- For the reaction $ep \rightarrow e'e^+e^-(p')$
- The missing four-momentum is defined as $p_X = p_e + p_p - p_{e^-} - p_{e^+} - p_{e'}$
- The peak on the distribution should be around the mass of the missing proton.
- We keep events with $E_\gamma > 8.1$ GeV where $E_\gamma = E_{beam} - E_{e'}$
- Invariant mass $M^2(e^-e^+) = (p_{e^-} + p_{e^+})^2$ should be in the 2.0 GeV to 3.5 GeV region
- We also apply a cut in the missing mass as $|M_X = 0.9609| < 3\sigma$
- $Q^2 < 0.1$ GeV^2 ($Q^2 = 0 - 0.1$ GeV^2)



Missing mass distribution for the final state $e'e^+e^-$.The peak correspond to the missing mass of the proton.

Courtesy of Mariana Tenorio Pita, Nov. 2024




NSTAR 2026
Once upon a Time, there
was a Vector Meson. . .

"November Revolution" or 50 yrs Discovery of J/ψ

@ East coast of US

Experimental Observation of a Heavy Particle J

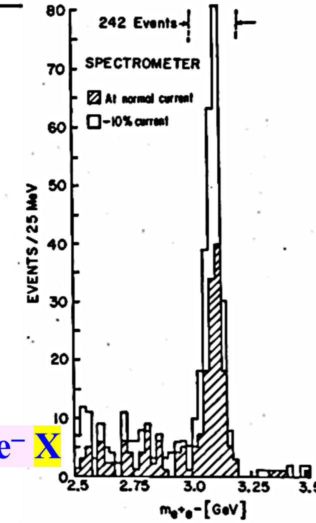
VOLUME 33, NUMBER 23 PHYSICAL REVIEW LETTERS 2 DECEMBER 1974

Experimental Observation of a Heavy Particle J†

J. J. Aubert, U. Becker, P. J. Biggs, J. Burger, M. Chen, G. Everhart, P. Goldhagen, J. Leong, T. McCorriston, T. G. Rhoades, M. Rohde, Samuel C. C. Ting Lan Wu
Laboratory for Nuclear Science and Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

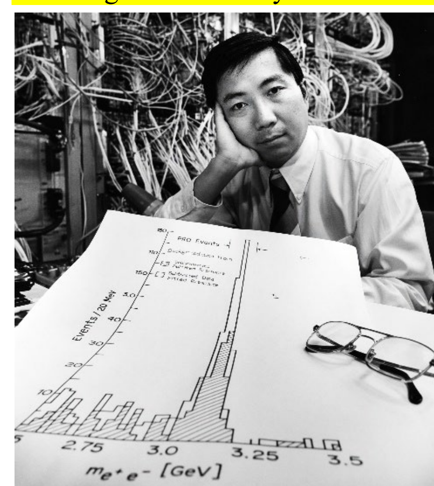
and

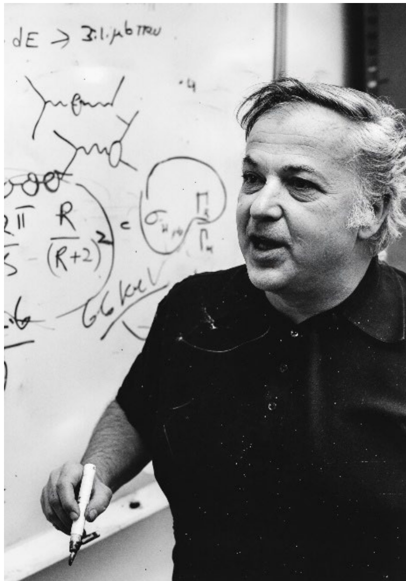
Y. Y. Lee
Brookhaven National Laboratory, Upton, New York 11973
(Received 12 November 1974)



p Be → $e^+ e^-$ X

J.-E. Augustin *et al*. Phys Rev Lett **33**, 1406 (**1974**)





@ West coast of US

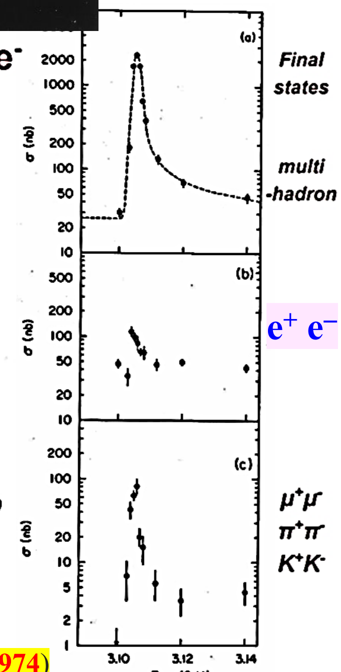
Discovery of a Narrow Resonance in e^+e^- Annihilation

Discovery of a Narrow Resonance in e^+e^- Annihilation*

J.-E. Augustin,† A. M. Boyarski, M. Breidenbach, F. Bulos, J. T. Dakin, G. J. Feldman, G. E. Fischer, D. Fryberger, G. Hanson, B. Jean-Marie,† R. R. Larsen, V. Lüth, H. L. Lynch, D. Lyon, C. C. Morehouse, J. M. Paterson, M. L. Perl, Burton Richter, Rapidis, R. F. Schwitters, W. M. Tanenbaum, and F. Vannucci‡
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305

and

G. S. Abrams, D. Briggs, W. Chinowsky, C. E. Friedberg, G. Goldhaber, R. J. Hollebeek, J. A. Kadyk, B. Lulu, F. Pierre,§ G. H. Trilling, J. S. Whitaker, J. Wiss, and J. E. Zipse
Lawrence Berkeley Laboratory and Department of Physics, University of California, Berkeley, California 94720
(Received 13 November 1974)



J.J. Aubert *et al*. Phys Rev Lett **33**, 1404 (**1974**)

- Existence of ϕ meson was first proposed by Sakurai in **1962** as resonance state between K^0 & $\bar{K}^0$.

VOLUME 9, NUMBER 11 PHYSICAL REVIEW LETTERS DECEMBER 1, 1962

POSSIBLE EXISTENCE OF A $T=0$ VECTOR MESON AT 1020 MeV†

J. J. Sakurai*

VOLUME 10, NUMBER 8 PHYSICAL REVIEW LETTERS 15 APRIL 1963

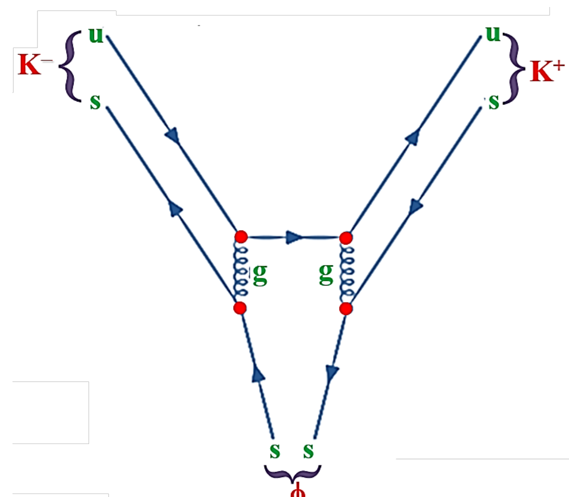
EXISTENCE AND PROPERTIES OF THE φ MESON*

P. L. Connolly, E. L. Hart, K. W. Lai, G. London,† G. C. Moneti,‡ R. R. Rau, N. P. Samios, I. O. Skillicorn, and S. S. Yamamoto

- ϕ -meson was discovered in **1963** in **20**-inch hydrogen BC AGS in ,
while they were studying **K⁻p** collisions @ ~**2.23** GeV/c.

$$K^- + p \to \Lambda + K^0 + \bar{K}^0$$

$$K^- + p \to \Lambda + K^+ + K^-$$



$\gamma^* N \to \phi N \to (K^+K^-)N$ *Measurements from* clas


PHYSICAL REVIEW C, VOLUME 63, 065205 (2001)

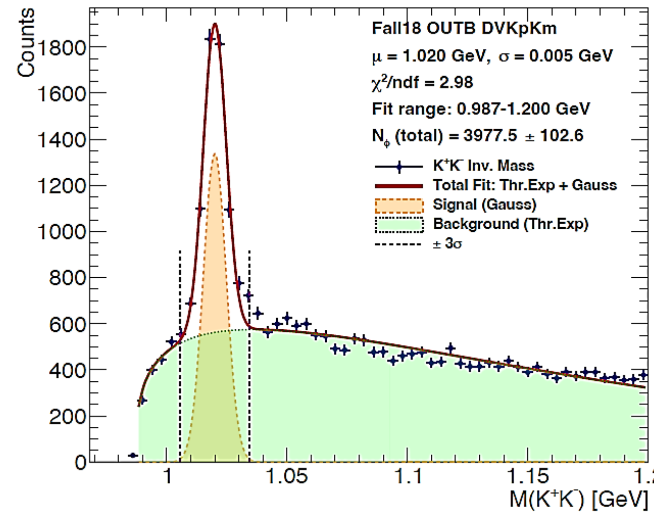
- **Exclusive electroproduction of ϕ mesons at 4.2 GeV**

K. Lukashin,[1,2,*] E. S. Smith,[2] G. S. Adams,[28] E. Anciant,[7] M. Anghinolfi,[15] B. Asavapibhop,[20] G. Audit,[7] T. Auger,[7] H. Avakian,[14] J. Ball,[3] S. Barrow,[13] M. Battaglieri,[15] K. Beard,[18] M. Bektasoglu,[25] W. Bertozzi,[21] N. Bianchi,[14]

PHYSICAL REVIEW C 78, 025210 (2008)

- **Electroproduction of $\phi(1020)$ mesons at $1.4 \leqslant Q^2 \leqslant 3.8$ GeV^2 measured with the CLAS spectrometer**

J. P. Santoro,[1,2] E. S. Smith,[3] M. Garçon,[4] M. Guidal,[5] J. M. Laget,[3] C. Weiss,[3] G. Adams,[35] M. J. Amaryan,[33] M. Anghinolfi,[22] G. Asryan,[43] G. Audit,[4] H. Avakian,[3] H. Bagdasaryan,[33,43] N. Baillie,[42] J. Ball,[4] J. P. Ball,[7] N. A. Baltzell,[39] S. Barrow,[17]

Courtesy of Bhawani Singh, Nov 2025


Contents lists available at ScienceDirect

ELSEVIER

Physics Letters B 680, 417 (2010)

www.elsevier.com/locate/physletb

- The extraction of ϕ–N total cross section from $d(\gamma, pK^+K^-)n$

CLAS Collaboration

X. Qian[a,*], W. Chen[a], H. Gao[a], K. Hicks[b], K. Kramer[a], J.M. Laget[c,d], T. Mibe[b], S. Stepanyan[d], D.J. Tedeschi[e], W. Xu[f], K.P. Adhikari[af], M. Amaryan[af], M. Anghinolfi[w], H. Baghdasaryan[am], J. Ball[c],

PHYSICAL REVIEW C 89, 055208 (2014)

- **Data analysis techniques, differential cross sections, and spin density matrix elements for the reaction $\gamma p \to \phi p$**

B. Dey,[1,*] C. A. Meyer,[1] M. Bellis,[1,†] M. Williams,[1,‡] K. P. Adhikari,[28] D. Adikaram,[28] M. Aghasyan,[17] M. J. Amaryan,[28] M. D. Anderson,[36] S. Anefalos Pereira,[17] J. Ball,[7] N. A. Baltzell,[3] M. Battaglieri,[18] I. Bedlinskiy,[21] A. S. Biselli,[11] J. Bono,[12]


Mystery of $\phi(1020)$

PDG particle data group

Citation: S. Navas *et al.* (Particle Data Group), Phys. Rev. D 110, 030001(2024)025 update

$\phi(1020)$ $\qquad I^G(J^{PC}) = 0^-(1^{--})$

● $\phi(1020)$ MASS

VALUE (MeV)	*EVTS*	*DOCUMENT ID*	*TECN*	*COMMENT*
1019.460 ±0.016 OUR AVERAGE				
1019.443 ±0.010 ±0.060	1.28M	[1] ACHASOV 24	SND	$e^+e^- \to K^0_L K^0_S$
1019.463 ±0.061	2.3M	[2] KOZYREV 18	CMD3	$e^+e^- \to K^+K^-$, $K^0_S K^0_L$

● $\phi(1020)$ WIDTH

VALUE (MeV)	*EVTS*	*DOCUMENT ID*	*TECN*	*COMMENT*
4.249±0.013 OUR AVERAGE		Error includes scale factor of 1.1.		
4.212±0.20 ±0.13	1.28M	[1] ACHASOV 24	SND	$e^+e^- \to K^0_L K^0_S$
4.245±0.013	2.3M	[2] KOZYREV 18	CMD3	$e^+e^- \to K^+K^-$, $K^0_S K^0_L$

● $\phi(1020)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Γ_1	K^+K^-	(49.9 ±0.5) %	S=1.5
Γ_2	$K^0_L K^0_S$	(33.6 ±0.4) %	S=1.3
Γ_3	$\rho\pi + \pi^+\pi^-\pi^0$	(14.9 ±0.4) %	S=1.3
Γ_4	$\pi^+\pi^-\pi^0$		
Γ_5	$\eta\gamma$	(1.306±0.024) %	S=1.2

N^*

Particle	J^P	overall	Status as seen in $N\gamma$	$N\pi$	$\Delta\pi$	$N\sigma$	$N\eta$	ΛK	ΣK	$N\rho$	$N\omega$	$N\eta'$
N	$1/2^+$	****										
$N(1440)$	$1/2^+$	****	****	****	****	***						
$N(1520)$	$3/2^-$	****	****	****	****	**	****					
$N(1535)$	$1/2^-$	****	****	****	***	*	****					
$N(1650)$	$1/2^-$	****	****	****	***	*	****	*				
$N(1675)$	$5/2^-$	****	****	****	****	***	*	*	*			
$N(1680)$	$5/2^+$	****	****	****	****	***	*	*	*			
$N(1700)$	$3/2^-$	***	**	***	***	*	*			*		
$N(1710)$	$1/2^+$	****	****	****	*		***	**	*	*	*	
$N(1720)$	$3/2^+$	****	****	****	***	*	*	****	*	*	*	
$N(1860)$	$5/2^+$	**	*	**		*	*					
$N(1875)$	$3/2^-$	***	**	**	*	**	*	*	*	*	*	
$N(1880)$	$1/2^+$	***	**	*	**	*	*	**	**		**	
$N(1895)$	$1/2^-$	****	****	*	*	*	****	**	**	*	*	****
$N(1900)$	$3/2^+$	****	****	**	**	*	*	**	**		*	**
$N(1990)$	$7/2^+$	**	**	**			*	*	*			
$N(2000)$	$5/2^+$	**	**	*	**	*	*				*	
$N(2040)$	$3/2^+$	*		*								
$N(2060)$	$5/2^-$	***	***	**	*	*	*	*	*	*	*	
$N(2100)$	$1/2^+$	***	**	***	**	**	*	*		*	*	**
$N(2120)$	$3/2^-$	***	***	**	**	**		**	*		*	*
$N(2190)$	$7/2^-$	****	****	****	****	**	*	**	*	*	*	
$N(2220)$	$9/2^+$	****	**	****			*	*	*			
$N(2250)$	$9/2^-$	****	**	****			*	*	*			
$N(2300)$	$1/2^+$	**		**								
$N(2570)$	$5/2^-$	**		**								
$N(2600)$	$11/2^-$	***		***								
$N(2700)$	$13/2^+$	**		**								

Δ^*

Particle	J^P	overall	Status as seen in $N\gamma$	$N\pi$	$\Delta\pi$	ΣK	$N\rho$	$\Delta\eta$
$\Delta(1232)$	$3/2^+$	****	****	****				
$\Delta(1600)$	$3/2^+$	****	****	***	****			
$\Delta(1620)$	$1/2^-$	****	****	****	****			
$\Delta(1700)$	$3/2^-$	****	****	****	****	*	*	
$\Delta(1750)$	$1/2^+$	*	*	*		*		
$\Delta(1900)$	$1/2^-$	***	***	***	*	**	*	
$\Delta(1905)$	$5/2^+$	****	****	****	**	*	*	**
$\Delta(1910)$	$1/2^+$	****	***	****	**	**		*
$\Delta(1920)$	$3/2^+$	***	***	***	***	**		**
$\Delta(1930)$	$5/2^-$	***	*	***	*	*		
$\Delta(1940)$	$3/2^-$	**	*	**	*			*
$\Delta(1950)$	$7/2^+$	****	****	****	**	***		
$\Delta(2000)$	$5/2^+$	**	*	**	*		*	
$\Delta(2150)$	$1/2^-$	*		*				
$\Delta(2200)$	$7/2^-$	***	***	**	***	**		
$\Delta(2300)$	$9/2^+$	**		**				
$\Delta(2350)$	$5/2^-$	*		*				
$\Delta(2390)$	$7/2^+$	*		*				
$\Delta(2400)$	$9/2^-$	**	**	**				
$\Delta(2420)$	$11/2^+$	****	*	****				
$\Delta(2750)$	$13/2^-$	**		**				
$\Delta(2950)$	$15/2^+$	**		**				

- There are baryons with BR to **N**ω & **N**ρ. If one can trust in LHCb pentaquarks, then we will have **NJ/ψ** Res.
  Then **question** is: why are there no baryons with **Nϕ** BR? Or have we not observed them yet?

- At first glance, no **Nϕ** yet, perhaps because **J/ψ** is easier to detect than **ϕ** through its decay to e^+e^- &/or $\mu^+\mu^-$.

- Presence of pentaquark with **Nϕ** branching (which contains $s\bar{s}$ pair) is not excluded.
  Problem is that it may have large width (Γ_{tot}), so it is not clearly visible. Some people say that there should be bound state in **Nϕ** potential. In the case of **N**ρ (**N**ω), these may be usual *qqq* states that create new light $\bar{q}q$ pair during decay.
  Problem is not exotic, but *large mass*; for example, width of N(1900) [3/2+] is about 250 MeV.
  Additionally, **OZI** suppressed for ordinary *qqq* states.


NSTAR 2026

Nanjing & Bonn Us,
& HAL
for J/ψ–P SL

J/ψ-p Scattering Length from HAL

Yan Lyu, Takumi Doi, Tetsuo Hatsuda, & Takuya Sugiura, PoS **LATTICE2024**, 103 (**2025**)

$\bar{c}cp \rightarrow p\,\bar{c}c$

channel	a_0 [fm]
N-$J/\psi(^4S_{3/2})$	$0.30(2)\left(^{+0}_{-2}\right)$
N-$J/\psi(^2S_{1/2})$	$0.38(4)\left(^{+0}_{-3}\right)$

- We make deal with **TWO** different quantities:
- **SL** "measured" via **VMD** in **$\gamma p \rightarrow Vp$**.
  VDM tries to connect two values (**$Vp \rightarrow Vp$** & **$\gamma p \rightarrow Vp$**) but due to "***young***" effect phenomenological & Lattice values are not the same.
  We deal with "***young***" (not finally formed) meson which as rule has smaller *radius* & smaller *Xsec*, that is smaller **SL**.
- Lattice HAL **SL** corresponding to initial **V** (in its equilibrium state) scattering.

- Crucial point for $\pi^- p \rightarrow Vn$ case (as J-PARC will measure) is that ***photon*** creates/produces $Q\bar{Q}$ pair @ POINT while in ***pion*** case we deal with two quarks separated one from another @ beginning.

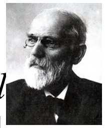
Revisited Vp Scattering Length

- In models & UNIVERSITÄT BONN, where interaction is mediated by heavy quark loop & two gluon exchange, these factors are accounted for automatically.
  Both groups calculated **SL**s for reactions **$\gamma p \to Vp$**,

- Whereas in Lattice they deal with $(\bar{c}c)$p elastic.
  Puzzle is that in $(\bar{c}c)$p case, SL is much larger. ***Young effect*** explains this puzzle.

- All previous ***theoretical*** results (including *potential* approaches & ***LQCD*** calculations) gave much-much larger ***SL***.

- Most probably, so large SL results from ***large distances tail*** of ***van der Waals*** *potential* which in QCD should be killed by *confinement*.



Courtesy of Yuri Dokshitzer, **2023**

- Evaluation of **$\gamma p \to J/\psi p$** Xsec of proton, which was reported by $007^{J/\psi}$ & clas,
  it is challenging to extend beyond our previous phenomenological determination of **J/ψp** SL.