Vector Meson Photoproduction at Threshold:
from Omega to Upsilon

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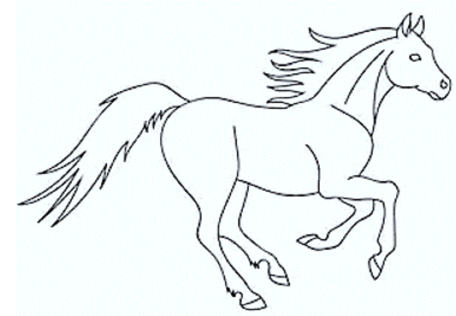
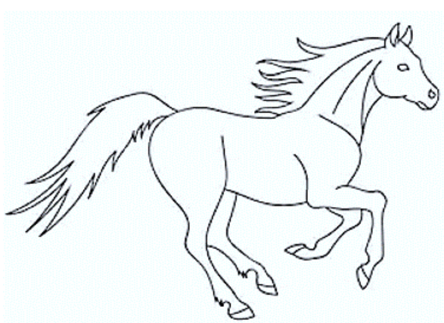
IS, S. Prakhov, Ya. Azimov *et al*, Phys Rev C **91**, 045207 (**2015**)
IS, D. Epifanov, & L. Pentchev, Phys Rev C **101**, 042201 (**2020**)
IS, L. Pentchev, & A.I. Titov, Phys Rev C **101**, 045201 (**2020**)
Meng-Lin Du, V. Baru, Feng-Kun Guo, Ch. Hanhart, U.-G. Meissner, A. Nefediev, & IS, Eur Phys J C **80**, 1053 (**2020**)
L. Pentchev & IS, Eur Phys J A **57**, 56 (**2021**)
IS, W.J. Briscoe, L. Pentchev, & A. Schmidt, Phys Rev C **104**, 074028 (**2021**)
Xiao-Yun Wang, Fancong Zeng, & IS, Phys Rev C **106**, 015202 (**2022**)

Supported by DE-SC0016583

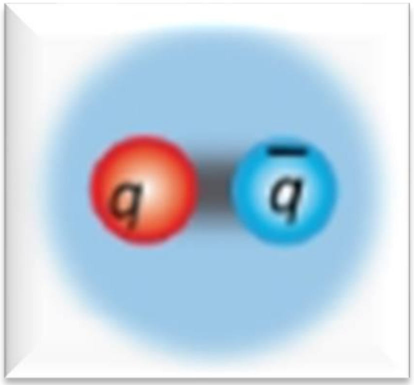
Outline



- *Vector meson* domestic *Zoo*.
- *Vector meson – nucleon SL.*
- *Threshold kinematics & Vector meson EM properties.*
- *VMD phenomenology.*
- *Brief tour through photoproduction experiments*.
    - *A2 & ELPH for* ω.
    - *JLab for* ϕ & J/ψ.
    - *EIC for* Υ & ψ'.
- *Vector meson – nucleon SLs.*
- *Outlook: A view of future.*



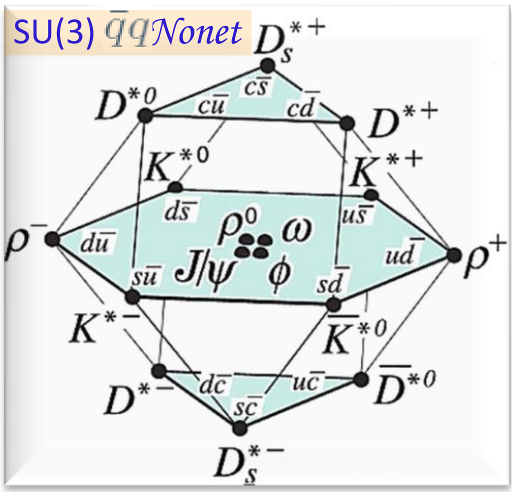
Vector Meson Domestic Zoo



Vector Meson Domestic 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*.

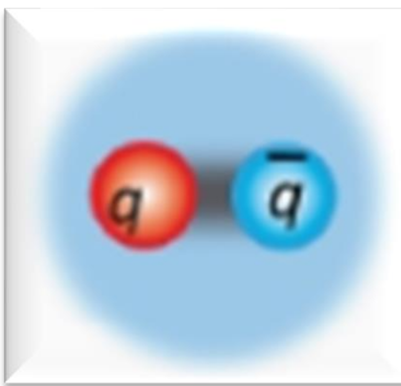
$I^G(J^{PC}) = 0^-(1^{--})$

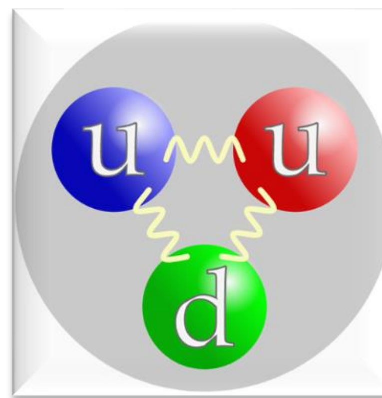


Name (PDG)	Quark Content	Γ (MeV)	
$\rho^+(770)$	$u\bar{d}$	148	
$\rho^0(770)$	$\frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d})$	149	
$\omega(782)$	$\frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d})$	8.5	
$K^{*+}(892)$	$u\bar{s}$	51	
$K^{*0}(892)$	$d\bar{s}$	47	
$\phi(1020)$	$s\bar{s}$	4.3	
$D^{*+}(2010)$	$c\bar{d}$	0.083	*Open Charm*
$D^{*0}(2007)$	$c\bar{u}$	< 2.1	
$J/\psi(1S)(3097)$	$c\bar{c}$	0.093	*Charmonium*
$\psi'(2S)(3686)$	$c\bar{c}$	0.284	
$\Upsilon(1S)(9460)$	$b\bar{b}$	0.052	*Quarkonium*

- We will focus on **5** ***vector mesons*** from $\bar{q}q$ ***Nonet*** which widths are **narrow** enough to study *meson photoproduction* @ threshold & where data are available.

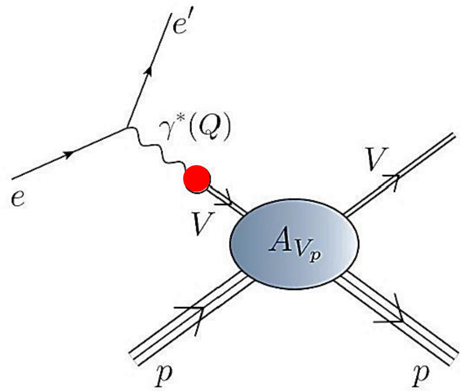
Vector Meson – Nucleon Scattering Length



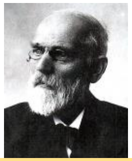


$Vp \to Vp$

- Don’t have *vector meson* beams, so experiments @ modern ***EM***-accelerators attempt to access such interactions via ***EM*** production reactions ***ep → e’Vp***.



- Interaction of ***heavy*** *vector mesons*, *J/ψ* or *Y*, with *proton* offers prospects for access to ***QCD van der Waals*** interaction, generated by multiple gluon exchange may relate to observation, *e.g.*, of *hidden-charm* ***5q*** states.

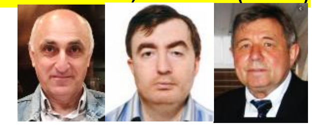


- ***Gluonic van der Waals*** interaction between color singlet hadrons can be described in *QCD* & is equivalent to *EM* interaction between two neutrally charged atoms.

Vector Meson – Nucleon Scattering Length Determination

IS, D. Epifanov, & L. Pentchev, Phys Rev C **101**, 042201 (**2020**)

IS, 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-threshold photoproduction *Xsections* of $\gamma p \to Vp$ & elastic $Vp \to Vp$

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

k is ***photon*** CM momentum $k = (s - M^2) / 2\, s^{1/2}$

q is *vector-meson* CM momentum

$q \to 0$

$T^{\gamma p\to Vp}$ is the invariant amplitude of *vector-meson* photoproduction

α is fine-structure constant

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

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

- Finally, one can express absolute value of *VN SL* as product of pure ***EM*** *VMD*-motivated kinematic factor

$$B_V^2 = \frac{\alpha\cdot m_V\cdot k}{12\pi\cdot\Gamma(V\to e^+e^-)}$$

PDG

& hadronic factor $h_{Vp} = \sqrt{b_1}$

where b_1 came from ***best fit***

$$\sigma_t(q) = b_1\cdot q + b_3\cdot q^3 + b_5\cdot q^5$$

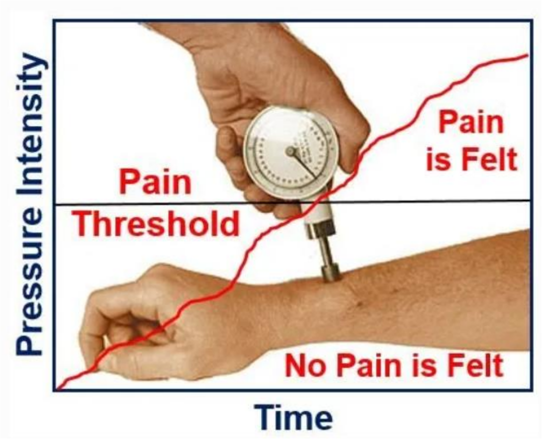
Experiment

that is determined by interplay of strong (*hadronic*) & ***EM*** dynamics as

$$|\alpha_{Vp}| = B_V\cdot h_{Vp}$$

- To *avoid* theoretical uncertainties, we did not
  - determine sign of ***SL***,
  - separate **Re** & **Im** parts of ***SL***,
  - extract *spin* **1/2** & **3/2** contributions.

Threshold Kinematics &
Vector Meson EM Properties



Kinematics for VM Photoproduction off Proton @ Thresholds & VM EM Properties

VMD coupling constant

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

EM factor

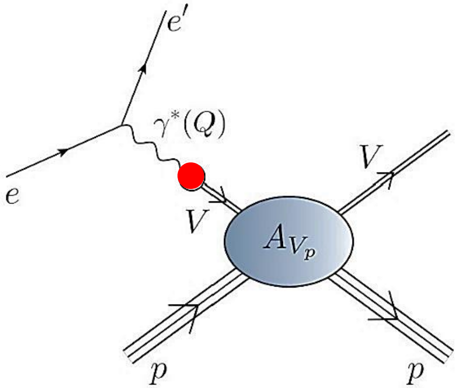
$$B_V^2 = \frac{\alpha \cdot m_V \cdot k}{12\pi \cdot \Gamma(V \to e^+ e^-)}$$

PDG particle data group

Vector Meson	m_V	W_{thr}	E_{thr}	k_{thr}	$\Gamma(V \to e^+e^-)$	g_V	B_V
	(MeV)	(MeV)	(MeV)	(MeV/c)	(keV)		($MeV^{1/2}$)
$\omega(762)$	782.65	1720.9	1109.1	604.7	0.60 ± 0.02	8.53 ± 0.14	390.49 ± 6.35
$\phi(1020)$	1019.461	1957.7	1573.3	754.0	1.27 ± 0.04	6.69 ± 0.10	342.50 ± 5.27
$J/\psi(1S)$	3096.900	4035.2	8207.8	1908.5	5.53 ± 0.10	5.59 ± 0.05	454.92 ± 4.06
$\psi'(2S)$	3686.1	4624.4	10926.7	2217.0	2.29 ± 0.06	9.47 ± 0.12	831.12 ± 108.88
$\Upsilon(1S)$	9460.30	10398.6	57152.9	5156.9	1.340 ± 0.018	19.85 ± 1.21	2654.96 ± 162.15

- *EM* factor B_V for low-lying *vector meson* is close to each other.

VMD Phenomenology



VMD Model

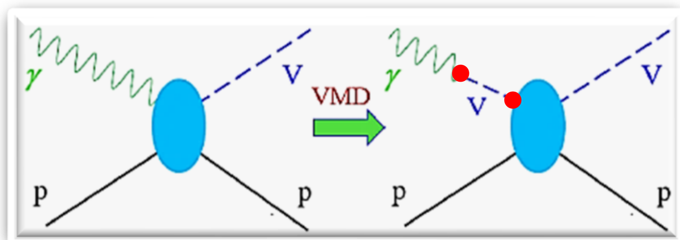
- *Vector Meson Dominance* model relying on transparent current-field identities

M. Gell-Mann & F. Zachariasen, Phys Rev **124**, 953 (**1961**)

J.J. Sakurai, *Currents and Mesons* (The University of Chicago Press, **1969**)

N.M. Kroll, T.D. Lee, & B. Zumino, Phys. Rev. **157**, 1376 (**1967**)

- In *VMD*, ***real photon*** can *fluctuate* into virtual ***vector meson***, which subsequently scatters off target proton.



- *VMD* does not contain *free parameters* & can be used for variety of qualitative estimates of observables in ***vector meson*** photoproductions @ least as first step towards their more extended theoretical studies.

VMD for *VN* *Interaction*

- There is no alternative *VMD* to get $J/\psi\, p$ *SL* from meson photoproduction.
  [Possible alternative is to develop sophisticated, nonperturbative reaction theory that can explain *quark+anti-quark* scattering from hadron targets into vector meson final-states.]

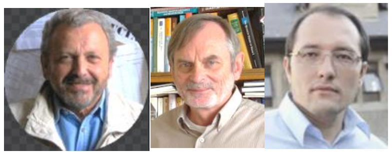
Courtesy of Arkady Vainshtein & Misha Ryskin, July **2020**

- To estimate theoretical uncertainty related to *VMD* model, one refer to estimation of cross section of J/ψ photoproduction in *peripheral model* & found strong energy dependence close to threshold because non-diagonal $\gamma p \to Vp$ & elastic $Vp \to Vp$ must have larger transfer momenta vs elastic scattering.
  This result in violation of *VMD* by factor of **5**.

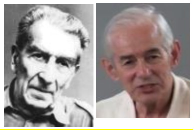
K.G. Boreskov & B.L. Ioffe, Sov J Nucl Phys **25**, 331 (**1977**)

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

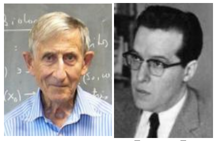
- Color factor for *charmonium* is **1**/**9** while for *open charm* is **8**/**9**.



- Strong suppression in *VN* interaction close to threshold is observed because of $\bar{q}q$ pair in point-like configuration lacks sufficient time to form complete wave function of vector meson;
  that is, proton interacts with "*young*" (undressed) *vector meson* whose size is smaller than that of "*old*" one participating in elastic $Vp \to Vp$ 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 as alternative interpretation of "*young age*" effect in another (more formal) language.

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

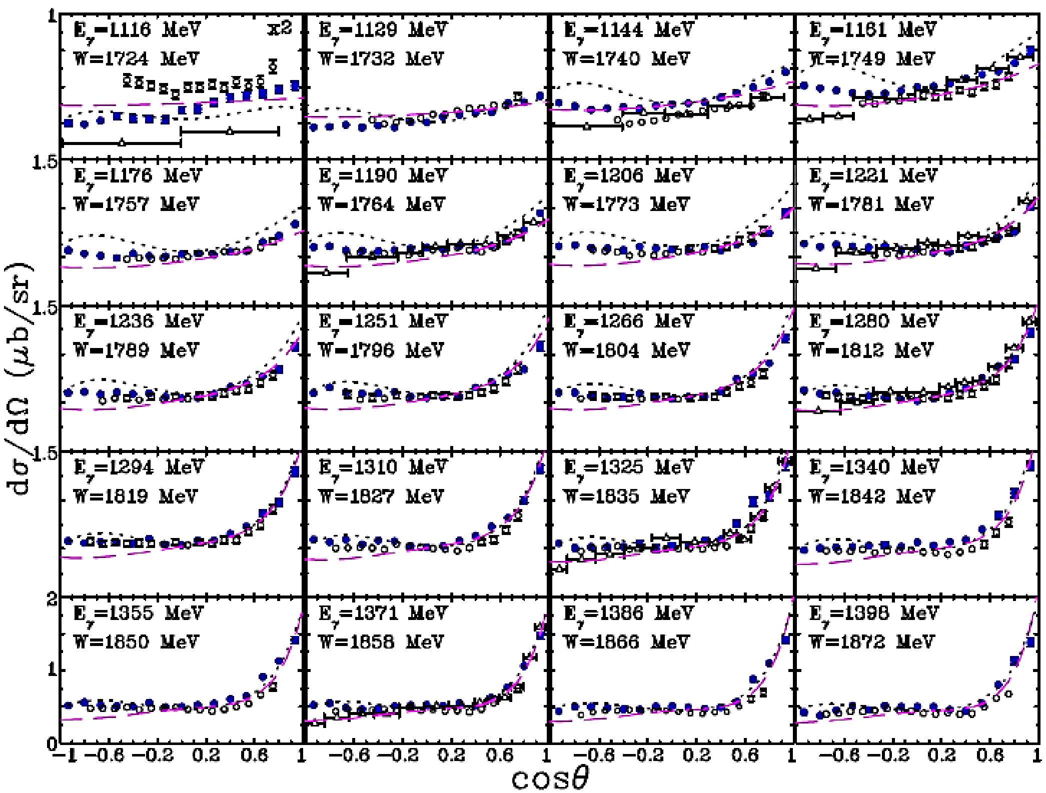
Brief Tour through Photoproduction Experiments

A2 & ELPH for Omega

$\gamma p \rightarrow \omega p \rightarrow \pi^0 \gamma p \rightarrow 3\gamma p$ Measurements

PDG BR($\omega \rightarrow \pi^0\gamma$) = 8.4%

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



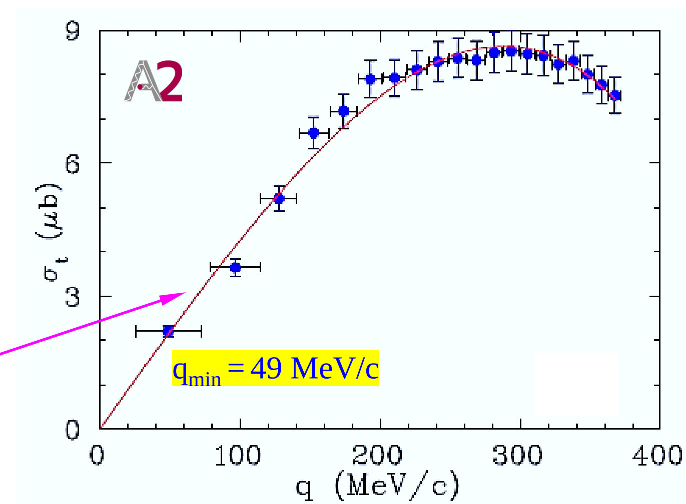
- Full production-angle coverage allows to determine σ_t.
- *Legendre* polynomial extension

$$d\sigma/d\Omega(E_\gamma, \cos\theta) = \sum_{j=0} A_j(E_\gamma) P_j(\cos\theta)$$

confirms σ_t determination

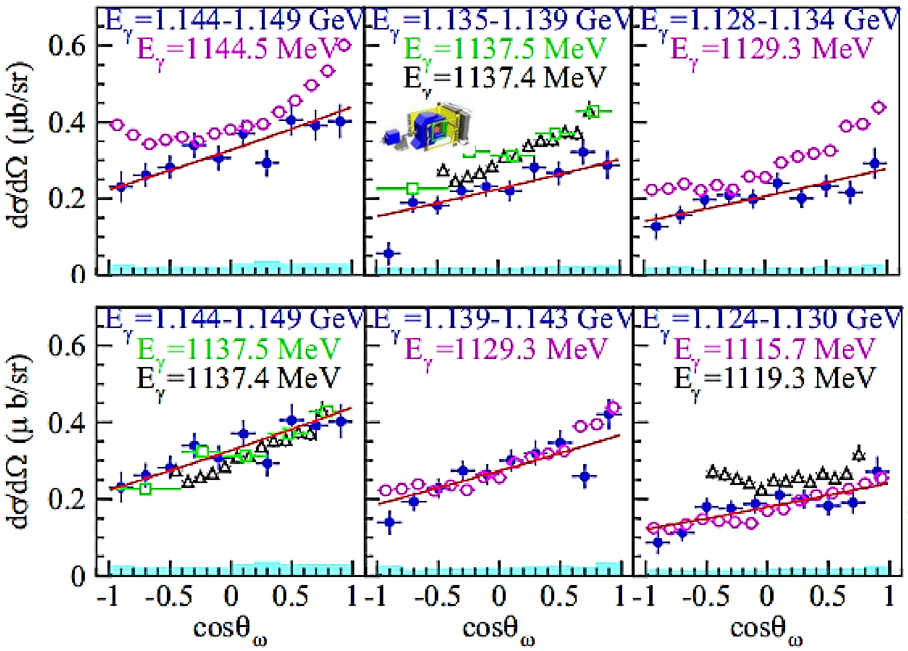
$$\sigma_t = 4\pi A_0(E_\gamma)$$

$$\sigma_t(q) = b_1 \cdot q + b_3 \cdot q^3 + b_5 \cdot q^5$$

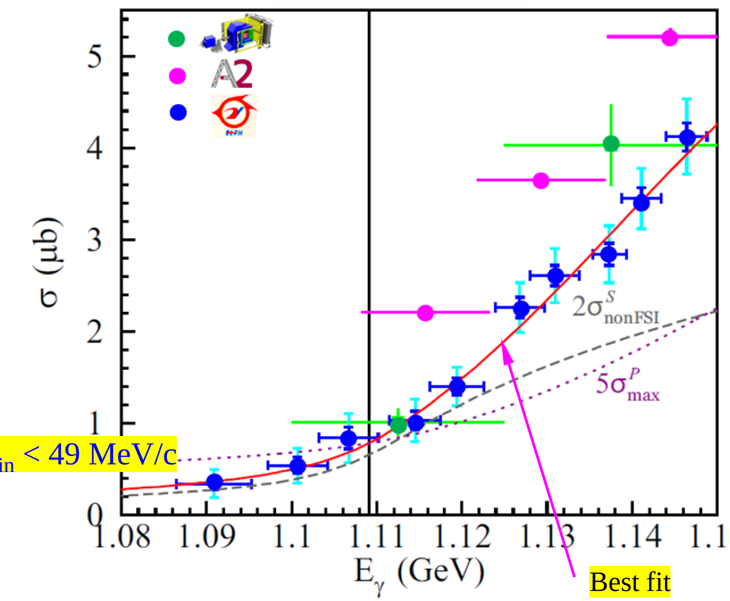


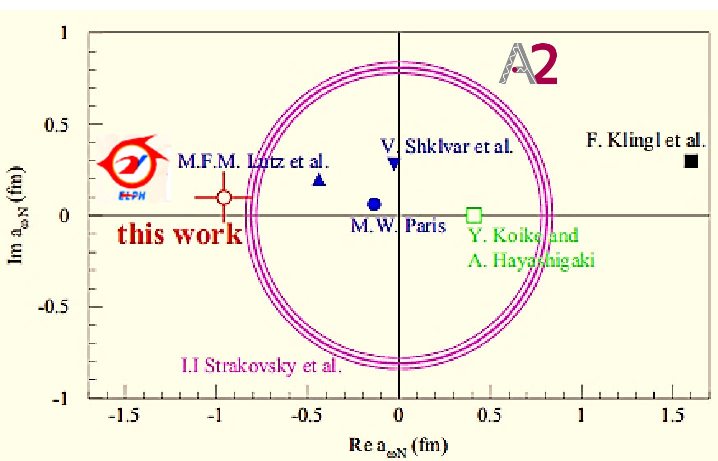
$\gamma p \rightarrow \omega p \rightarrow \pi^0 \gamma p \rightarrow 3\gamma p$ Measurements

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



$$\sigma = \sum 2\pi\,\Delta\cos\theta\,\frac{d\sigma}{d\Omega}$$

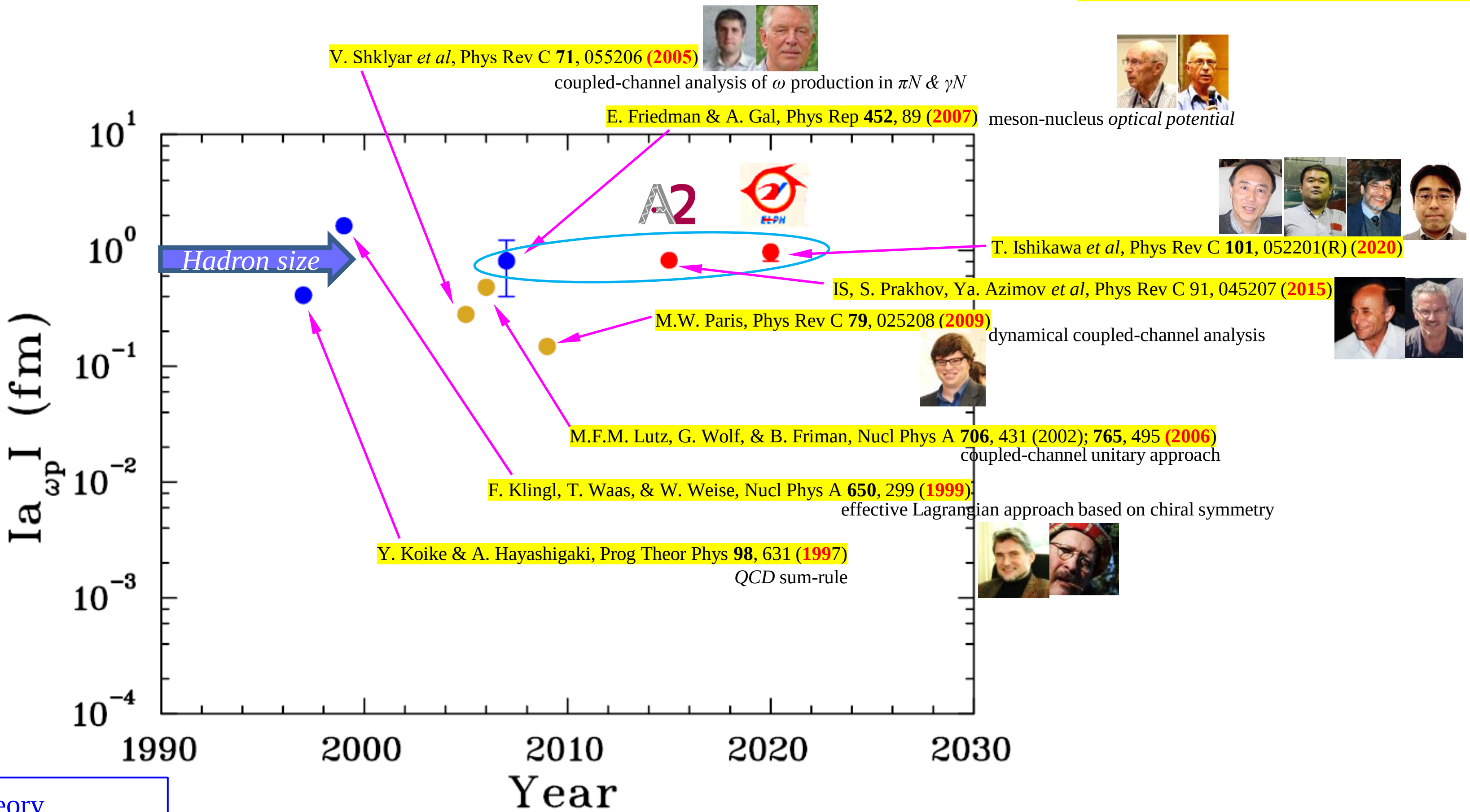




- *VMD* was not applicable in this case
- Determination of ***SL*** from excitation function of stot as function of ***q***.
- They evaluated excitation function using model with final-state ***ωp*** interaction based on ***Lippmann-Schwinger*** equation.
- They assumed that ***S***-wave contribution is dominant @ threshold incident pion momenta.

What is Known for ωN Scattering Length

- To *avoid* theoretical uncertainties, we did not
  - determine sign of *SL*,
  - separate Re & Im parts of *SL*,
  - extract *spin* 1/2 & 3/2 contributions.

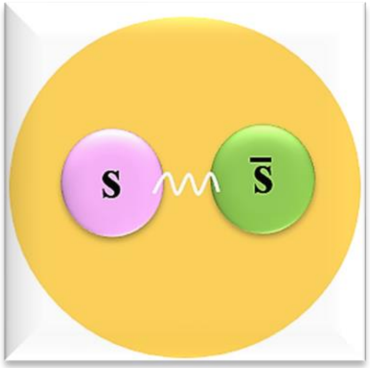


Theory
~~LQCD~~
PWA
Phenomenology

- *ωp SL* agrees with ***size*** of hadron.

JLab for Phi & J/Psi

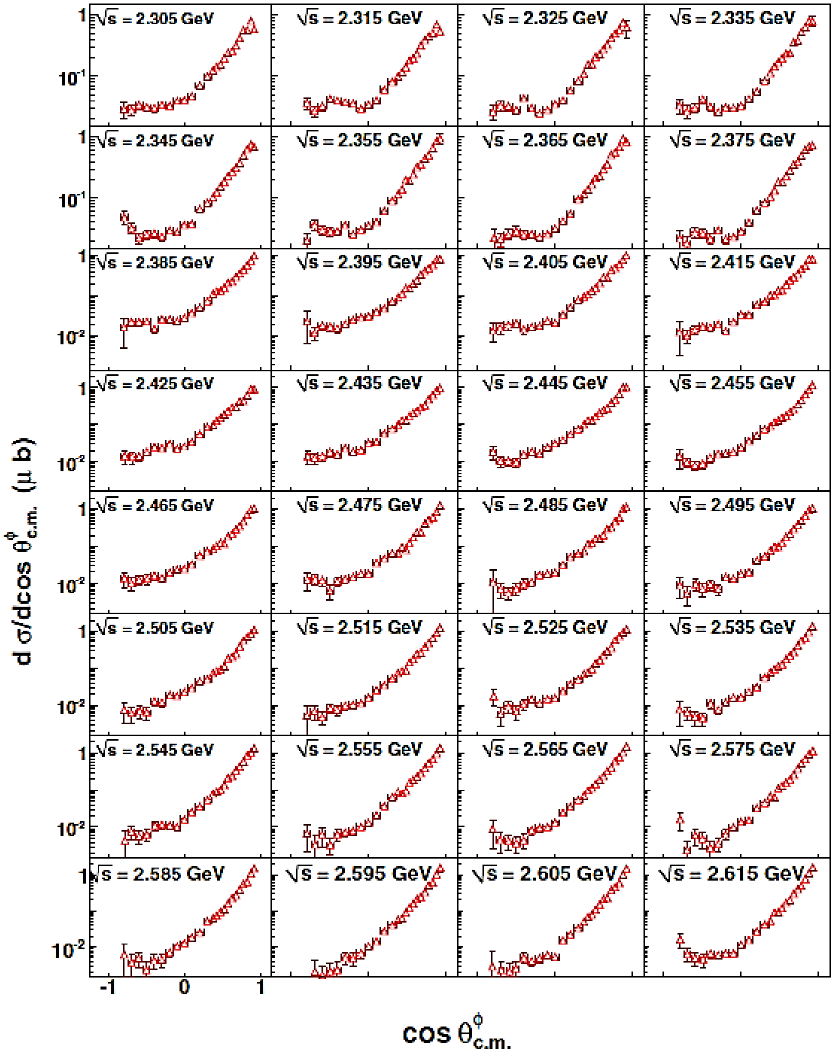
JLab for Phi



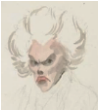
$\gamma p \longrightarrow \phi p \longrightarrow K^+K^-p$ Measurements

PDG BR($\phi \to K^+K^-$) = 49.2%

B. Dey *et al*, Phys Rev C **89**, 055208 (2014)

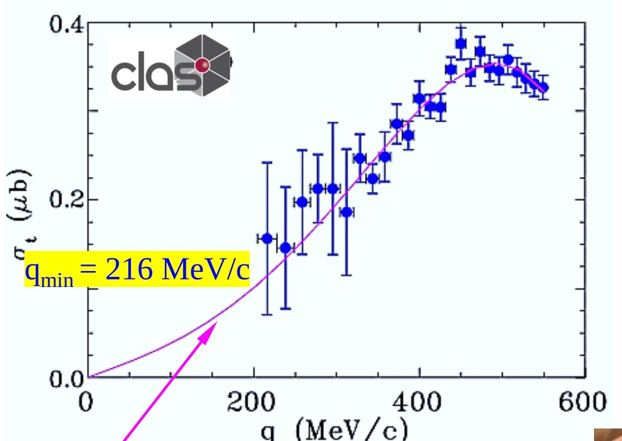


- ***cosθ*** of CLAS spans from -0.80 to 0.93.
- *Legendre* polynomial extension



$$d\sigma/d\Omega(E_\gamma, \cos\theta) = \sum_{j=0} A_j(E_\gamma)P_j(\cos\theta)$$

is way to determine σ_t $\quad \sigma_t = 4\pi A_0(E_\gamma)$

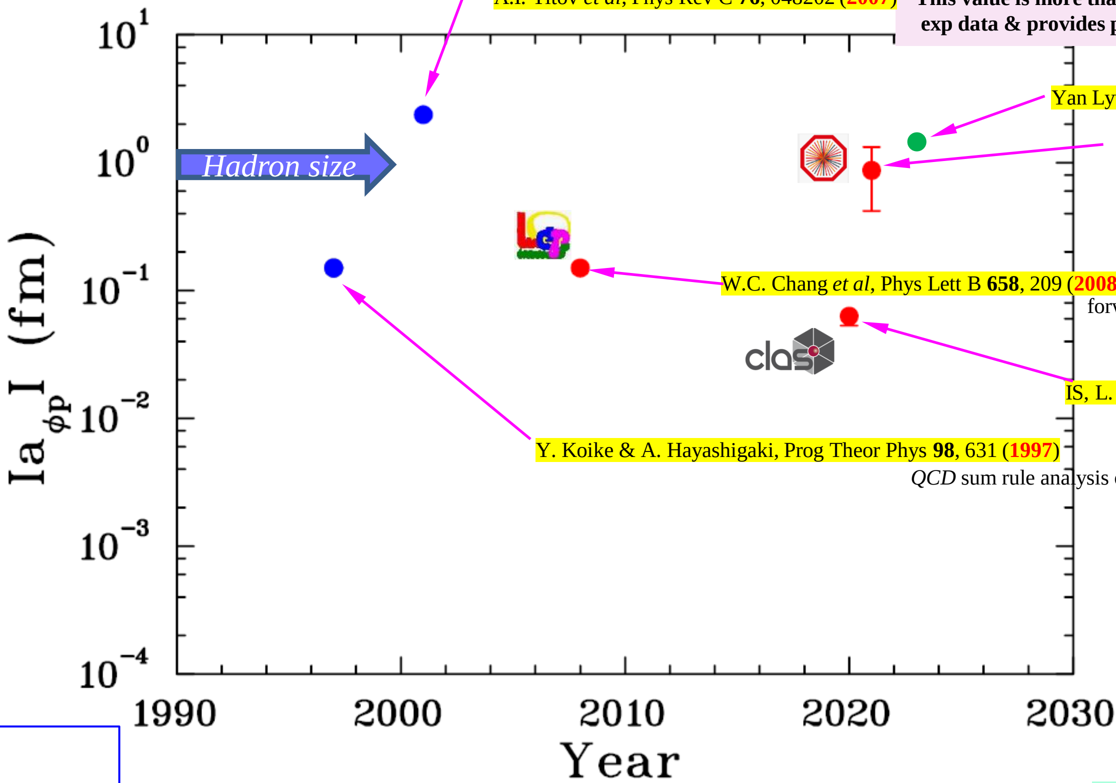


$$\sigma_t(q) = b_1 \cdot q + b_3 \cdot q^3 + b_5 \cdot q^5$$

IS, L. Pentchev, & A.I. Titov, Phys Rev C **101**, 045201 (2020)

What is Known for ϕN Scattering Length

- To *avoid* theoretical uncertainties, we did not
  - determine sign of *SL*,
  - separate Re & Im parts of *SL*,
  - extract *spin* 1/2 & 3/2 contributions.



H. Gao, T.S.H. Lee, & V. Marinov, Phys Rev C **63**, 022201 (**2001**)

QCD van der Waals attractive ϕN potential for analysis of ϕ-nucleus bound states

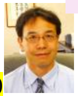
A.I. Titov *et al*, Phys Rev C **76**, 048202 (**2007**)

This value is more than order of magnitude greater than results using exp data & provides problem for this particular potential model.

Yan Lyu *et al* arXiv:2205.10544 [hep-lat] $\alpha(3/2)$

S. Acharya *et al*, Phys Rev Lett **127**, 172301 (**2021**)

We do not know $p\phi$ separation well, analysis used r ~ 1 fm



W.C. Chang *et al*, Phys Lett B **658**, 209 (**2008**)

forward coherent ϕ-meson photoproduction from deuterons near threshold

No uncertainties in *SL*

IS, L. Pentchev, & A.I. Titov, Phys Rev C **101**, 045201 (**2020**)

Y. Koike & A. Hayashigaki, Prog Theor Phys **98**, 631 (**1997**)

QCD sum rule analysis on spin-isospin averaged ρ, ω, & ϕ meson-nucleon scattering

Theory
LQCD
~~PWA~~
Phenomenology

- Our knowledge about ϕp *SL* is limited.
- No *PWA*

Is Final-State-Interaction Correlation Alternative to "Young" Effect?

- Recently, Collaboration reported alternative value of ***ϕN SL***

$$\mathrm{Re}(\alpha_{\phi \mathrm{N}}) = (0.85 \pm 0.34_{stat} \pm 0.14_{syst})\ \mathrm{fm}$$
$$\mathrm{Im}(\alpha_{\phi \mathrm{N}}) = (0.16 \pm 0.10_{stat} \pm 0.34_{syst})\ \mathrm{fm}$$

S. Acharya *et al*, Phys Rev Lett **127**, 172301 (**2021**)

- result was obtained from two-particle correlations of combined $p-\phi \oplus \overline{p}-\phi$ pairs measured in high-multiplicity **pp** collisions at **W = 13 TeV**.

- ***SL*** analysis assumed that proton and *ϕ*-meson produced independently @ distance about **1 fm**. While this distance is unknown.

- Another problem is that it is practically impossible to observe ***p-ϕ*** correlation (@ very small ***p-ϕ*** energy; *i.e.*, near threshold) @ (with or another detector).

- Overall, deals either with completely formed *ϕ*-meson or with $s\bar{s}$ pair with larger $s\bar{s}$ quarks separation (not with $s\bar{s}$ pair created by photons @ point).

Courtesy of Misha Ryskin, July **2022**

Recent LQCD Results

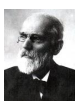
- Recently, Lattice group reported: $|\alpha^{3/2}_{\phi N}| = (1.43 \pm 0.23_{stat} \pm^{+0.36_{syst}}_{-0.06_{syst}})$ fm
- LQCD calculations, indeed, account for whole dynamics (up to their accuracy) & if they will calculate $\gamma p \rightarrow \phi p$ process they should reproduce observed cross section (which near threshold was fitted with very small ***SL***. Y. Lyu *et al*, Phys Rev D **106**, 074507 (2022)
- On other hand, LQCD calculations for elastic $\phi p \rightarrow \phi p$ scattering gave large ***SL***.
- One can proposing to LQCD groups to make deal not with vector meson but with $\bar{q}q$ pair which has same quantum numbers as corresponding vector meson (but not its WF).
- This pair becomes vector meson after some time needed to form vector meson WF.

- To extend this study, HAL reported

$$\mathrm{Re}(\alpha^{1/2}_{\phi N}) = (-1.47^{+0.44_{stat}}_{-0.37_{stat}} {}^{+0.14_{syst}}_{-0.17_{syst}})\ \mathrm{fm}$$
$$\mathrm{Im}(\alpha^{1/2}_{\phi N}) = (0.00^{+0.26_{stat}}_{-0.00_{stat}} {}^{+0.15_{syst}}_{-0.00_{syst}})\ \mathrm{fm}$$

E. Chizzali *et al*, arXiv: 2212.12690 [nucl-ex]

- To combine both LQCD results for spin **3/2** and **1/2** one can get a very large $|\alpha_{\phi N}|$ ***SL***.



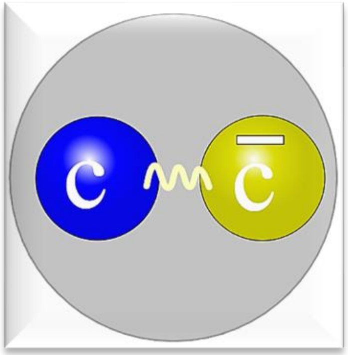

- QCD van der Waals attractive ϕN potential for analysis of ***ϕ-nucleus*** bound states that was reported H. Gao, T.S.H. Lee, & V. Marinov, Phys Rev C **63**, 022201 (2001)
- Then $|\alpha_{\phi N}|$ ***SL*** for this case, was found via direct solution of Schrodinger equation A.I. Titov *et al*, Phys Rev C **76**, 048202 (2007)

  $|\alpha_{\phi N}|$ = 2.37 fm leads to more than order of magnitude greater than results using experimental data & provides problem for this potential model.
- clas data, which came later, proves it.



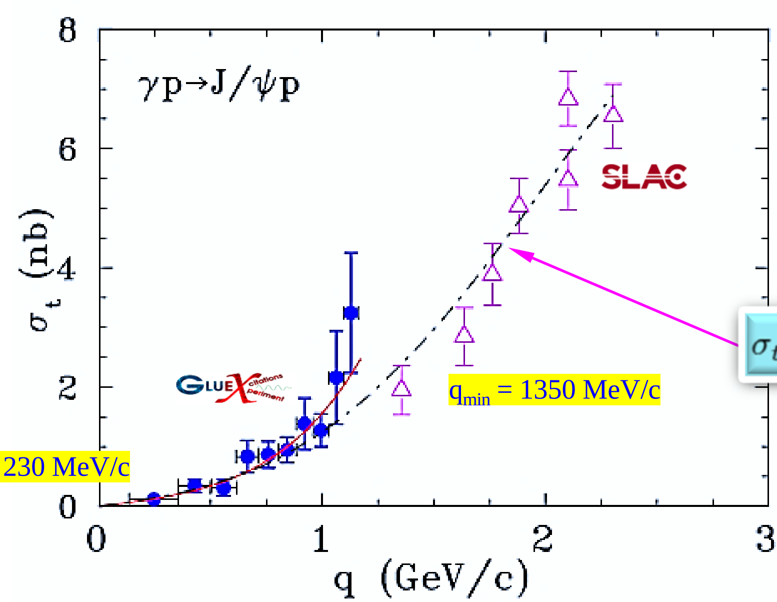
Courtesy of Misha Ryskin, July 2022

JLab for J/Psi



New J/ψ-p Scattering Length

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



$$\sigma_t(q) = b_1 \cdot q + b_3 \cdot q^3 + b_5 \cdot q^5$$

a_i	GlueX	GlueX & SLAC
a_1 [nb/(GeV/c)]	0.46 ± 0.16	0.53 ± 0.12
a_3 [nb/(GeV/c)^3]	0.83 ± 0.91	0.78 ± 0.16
a_5 [nb/(GeV/c)^5]	0.28 ± 0.87	-0.06 ± 0.03
χ^2/dof	0.67	0.98

- There is *no discrepancy* between

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

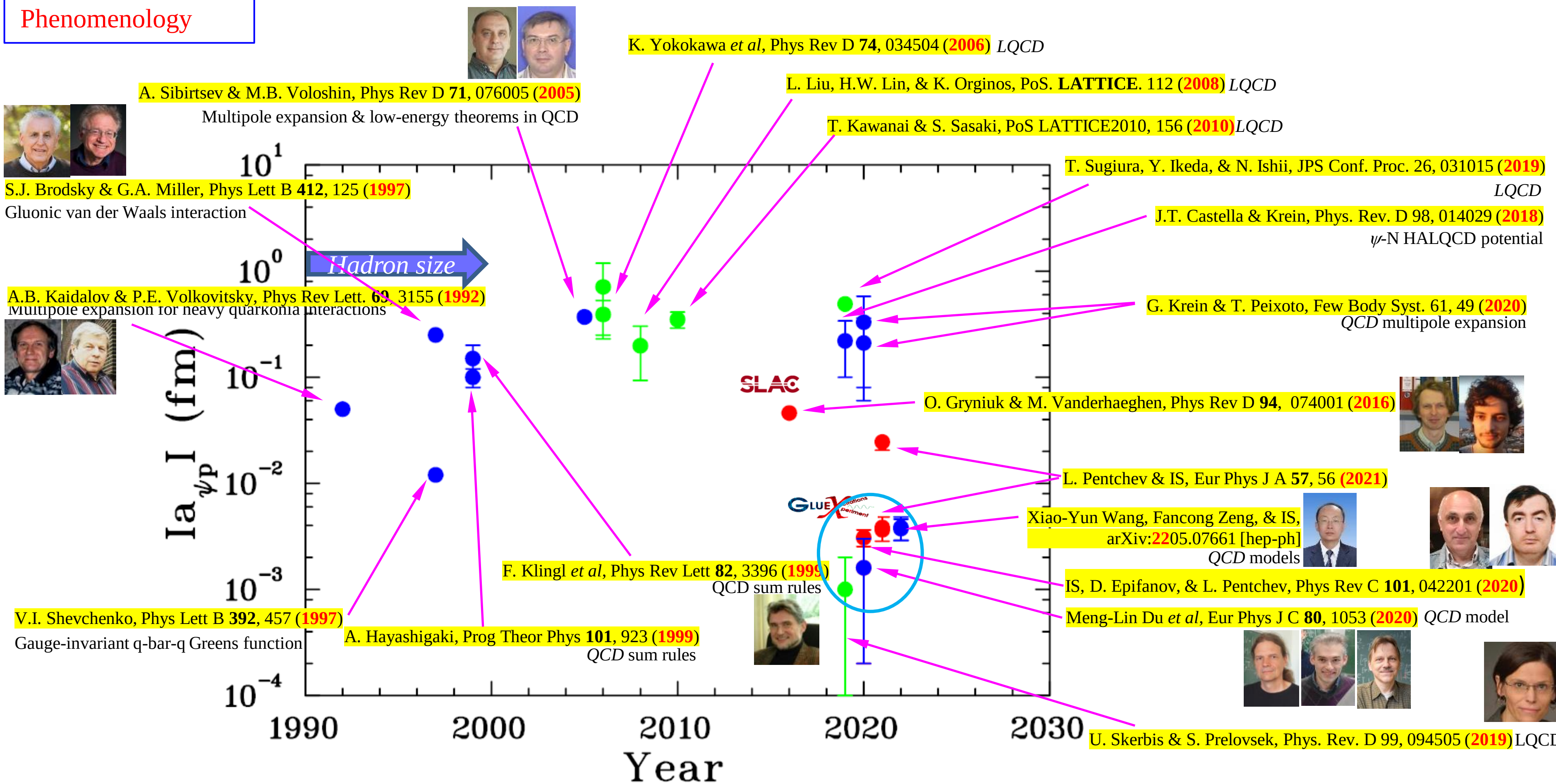
&

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

What is known for $J/\psi p$ Scattering Length

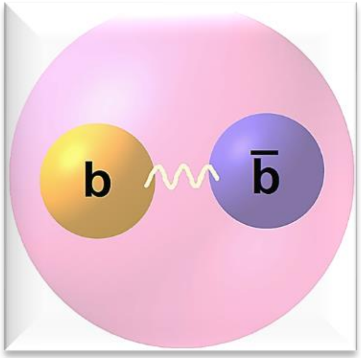
- To *avoid* theoretical uncertainties, we did not
  - determine sign of *SL*,
  - separate Re & Im parts of *SL*,
  - extract *spin* 1/2 & 3/2 contributions.

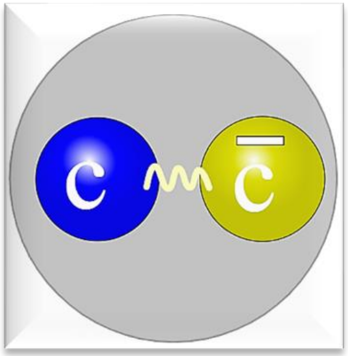
Theory
LQCD
~~PWA~~
Phenomenology



- Our result for $J/\psi p$ *SL* disagrees with theoretical predictions individually, though it is within wide range of these predictions.
- They do not consider "*young*" meson effect.

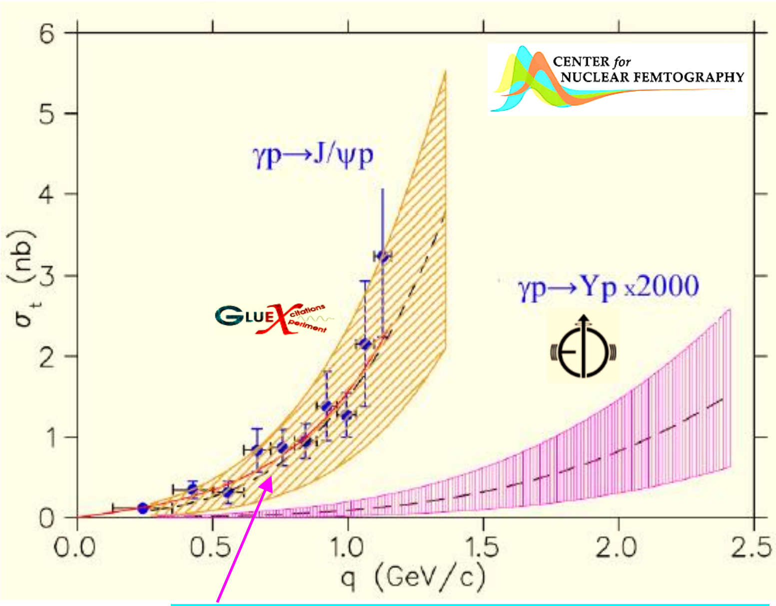
EIC for Upsilon & Psi'





Expectation from

IS, W.J. Briscoe, L. Pentchev, & A. Schmidt, Phys Rev C **104**, 074028 (**2021**)



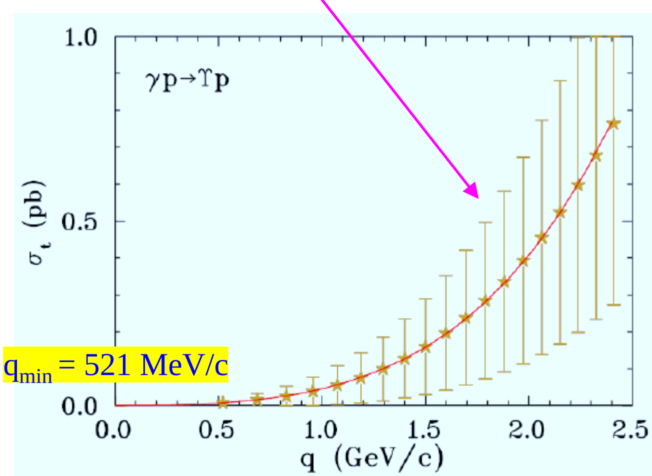
- Theoretical fit of GlueX data @ 95% C.L.

- *QCD* production amplitude can be factorized in terms of *gluonic generalized parton distributions* (*GPD*) & ***quarkonium*** distribution amplitude on one side & hard *quark-gluon* interaction on other side.

Y. Guo, X. Ji, & Y. Liu, Phys Rev D **103**, 096010 (**2021**)

- Just *theoretical* uncertainties.
- *Experimental* uncertainties depend on luminosity, detector acceptance, & efficiency.
- One can expect enormous ***Υ*** rate, & uncertainties will be comparatively small.

- *Quasi-data* were generated using ***QCD*** approach using detector properties.
- Further optimization of the low-Q^2 taggers may allow even smaller q_{min} to be achieved.

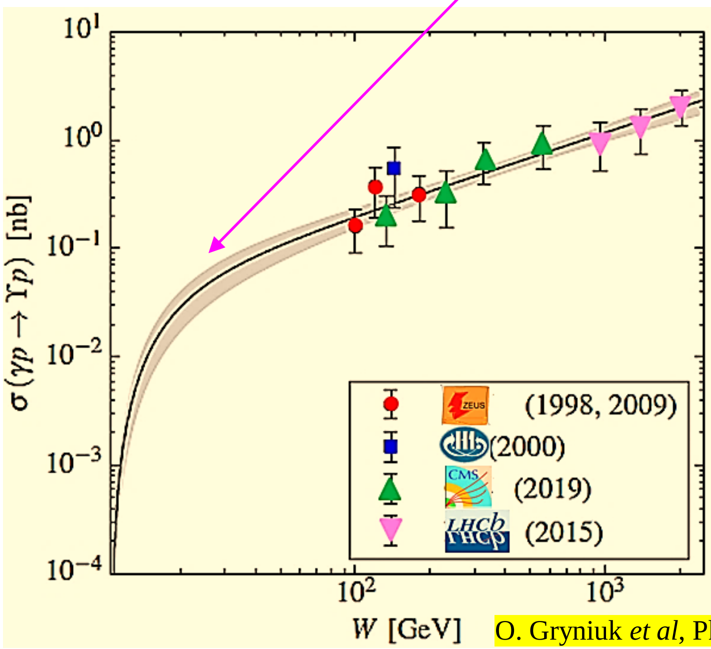


- It was assumed total integrated luminosity of 100 fb^{-1} for photoproduction @ , which corresponds to 116 days of beam with 10^{34} cm^{-2} s^{-1}, for MC calculations.

O. Gryniuk *et al*, Phys Rev D **102**, 014016 (**2020**)

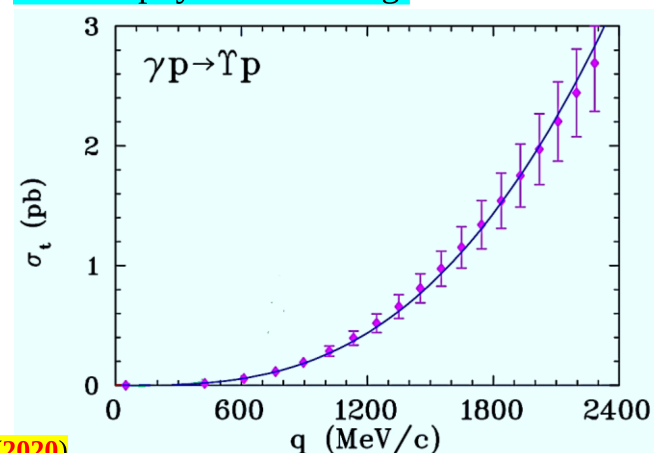
Alternative Expectation from

- Extrapolation goes down from **100 GeV** using ***2g*** exchange which disagreed with GlueX J/ψ threshold data.



O. Gryniuk *et al*, Phys Rev D **102**, 014016 (**2020**)

- One cannot use it because coefficient ***b_1*** has unphysical meaning.

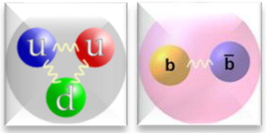


$|\alpha_{\Upsilon p}|$ = **0.066**±0.001 fm

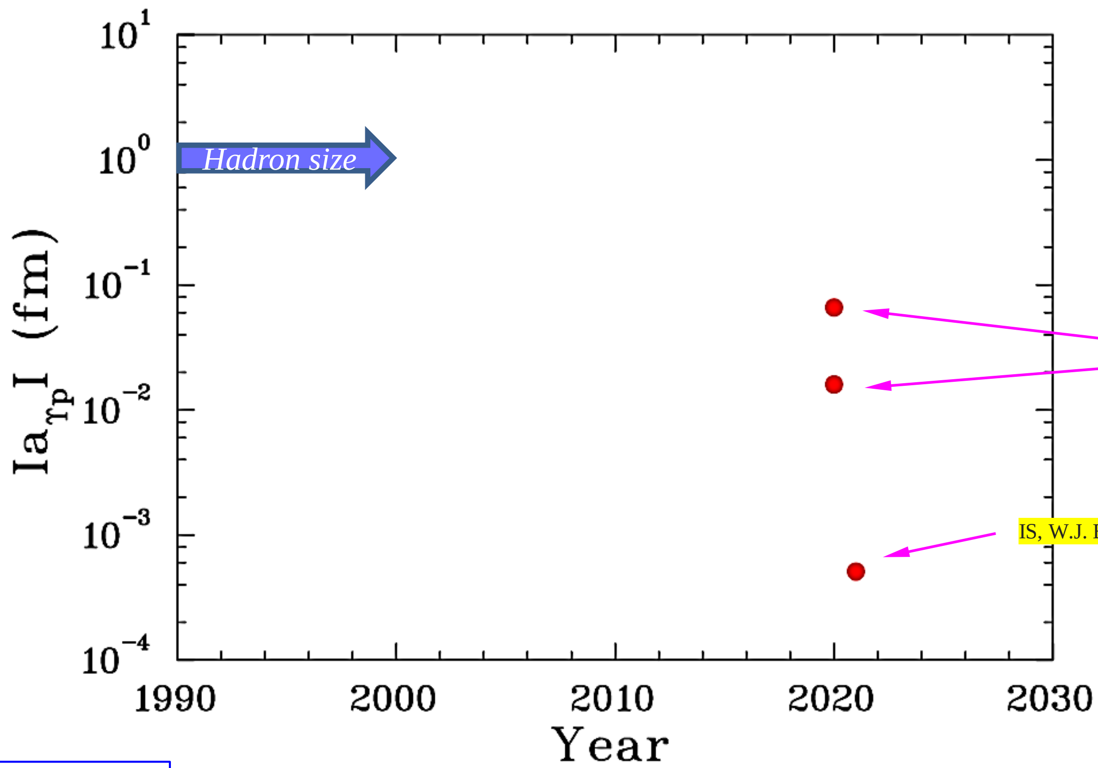
or

$|\alpha_{\Upsilon p}|$ = **0.016**±0.001 fm

Factor of difference with our phenomenology is 600 or 150



What may be known for Υp Scattering Length



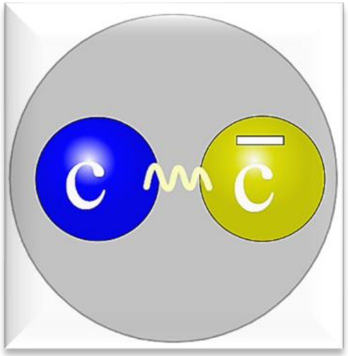
O. Gryniuk *et al*, Phys Rev D **102**, 014016 (**2020**)

IS, W.J. Briscoe, L. Pentchev, & A. Schmidt, Phys Rev C **104**, 074028 (**2021**)

~~Theory~~
~~LQCD~~
~~PWA~~
Phenomenology

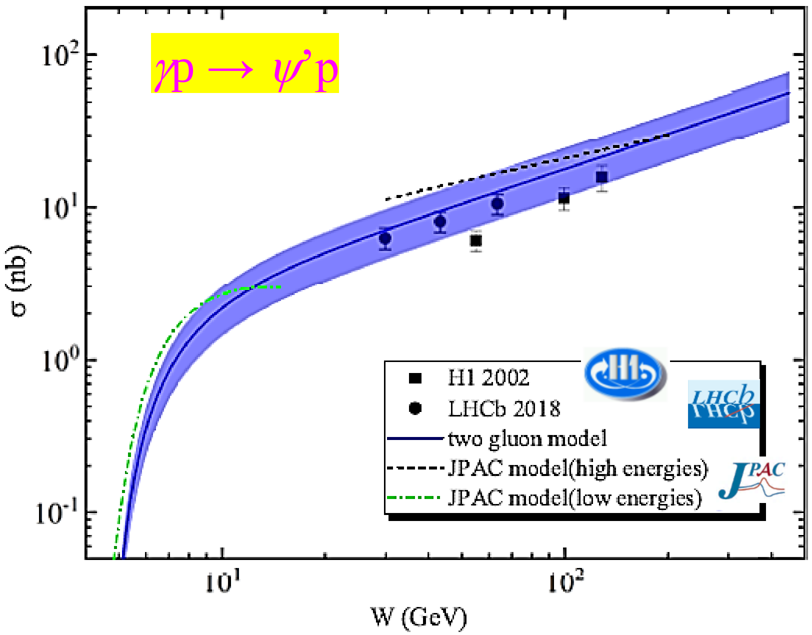
- Not so much known about *Υ*p *SL*.

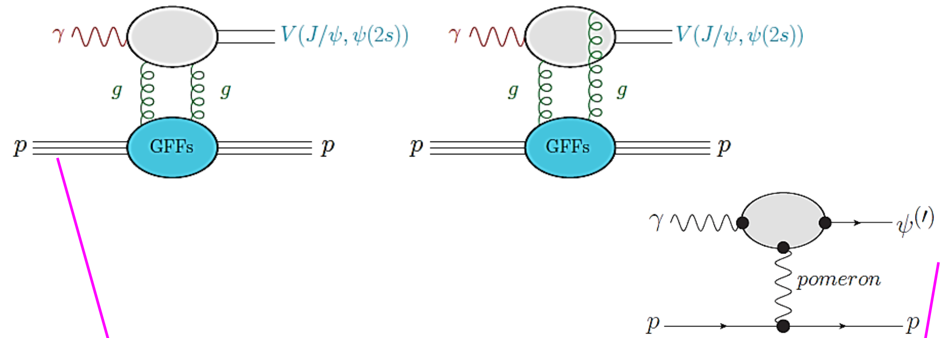
EIC for Psi'



Expectation from

Xiao-Yun Wang, Fancong Zeng, & Quanjin Wang [arXiv: 2204.07294 [hep-ph[]



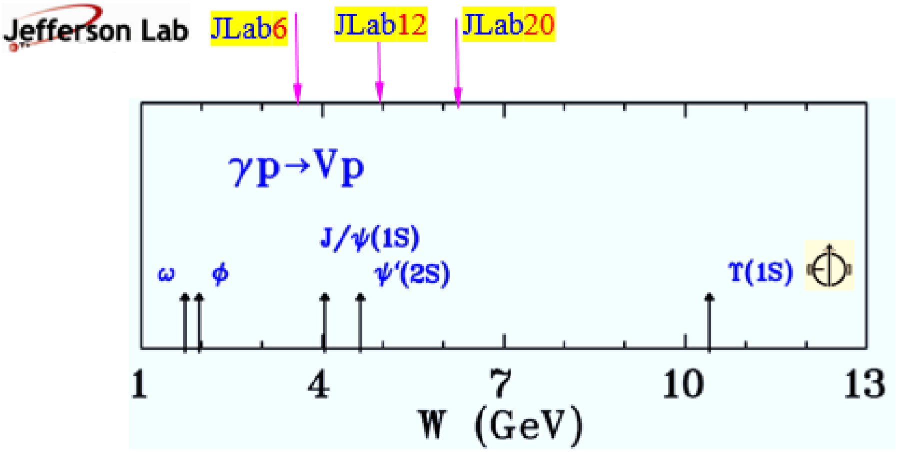


Method	$\lvert\alpha_{\psi'(2S)p}\rvert$
2g exchange model	1.31 ± 0.92
Effective Pomeron Model	3.24 ±0.63

Xiao-Yun Wang, Fancong Zeng, & IS , Phys Rev C **106**, 015202 (2022)

- Masses of $\psi'(2S)$ & $J/\psi(1S)$ are close to each other but due to another ***radial wave function***, *SL*s will be different.
- Phenomenological $J/\psi(1S)$ *SL* agrees with theoretical $\psi'(2S)$ *SL*.

Vector Meson – Nucleon SL



Total Cross Sections for Vector Meson Photoproduction off Proton

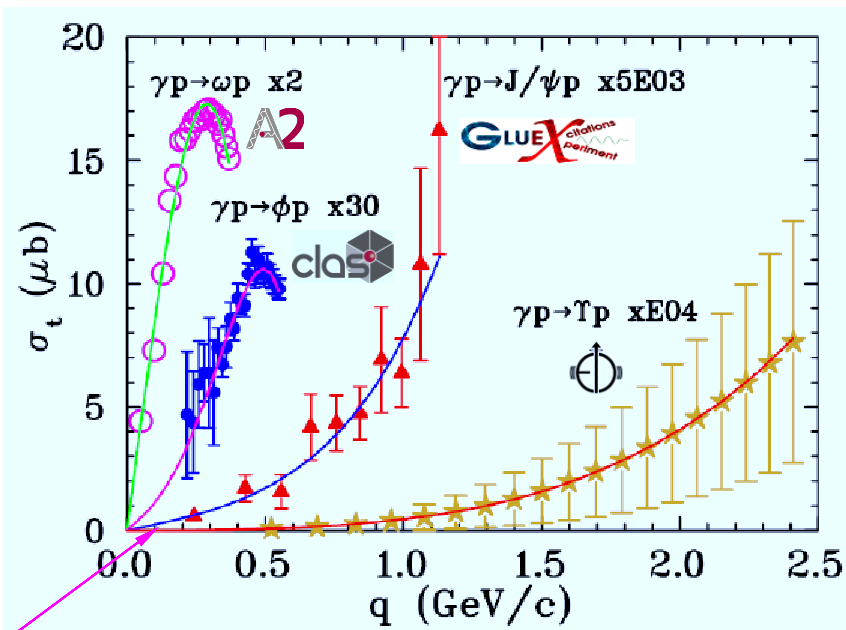
- Traditionally, σ_t behavior of near-threshold binary *inelastic* reaction

$$m_a + M_b < m_c + M_d$$

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

$$\sigma_t(q) = b_1 \cdot q + b_3 \cdot q^3 + b_5 \cdot q^5$$

- ***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 is no *VN* ***bound state*** below experimental q_{min}.

A2: b_1 = (**4.42**±0.14) x 10^{-2} μb/(MeV/c)
IS, S. Prakhov, Ya. Azimov *et al*, Phys Rev C **91**, 045207 (**2015**)

CLAS: b_1 = (**3.40**±1.15) x 10^{-4} μb/(MeV/c)
IS, L. Pentchev, & A.I. Titov, Phys Rev C **101**, 045201 (**2020**)

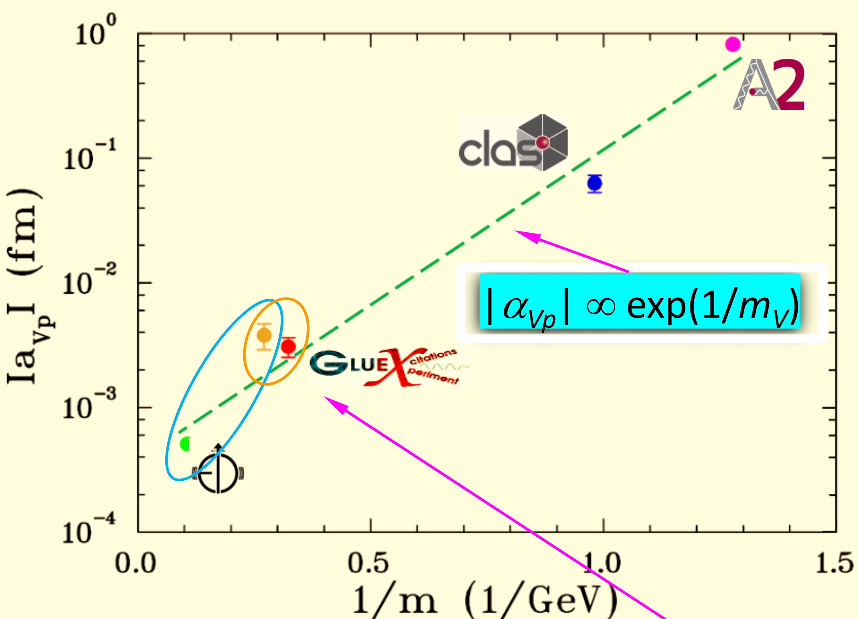
GlueX: b_1 = (**0.46**±0.16) x 10^{-6} μb/(MeV/c)
IS, D. Epifanov, & L. Pentchev, Phys Rev C **101**, 042201 (**2020**)

b_1 = (**0.37**±0.04) x 10^{-9} μb/(MeV/c)
IS, W.J. Briscoe, L. Pentchev, & A. Schmidt, Phys Rev C **104**, 074028 (**2021**)

- Dramatic differences in hadronic factors $h_{Vp} = \sqrt{b_1}$, as slopes (b_1) of σ_t @ threshold as function of q varies significantly from ω to ϕ to J/ψ.

- Therefore, such big difference in *Scattering Length* is determined mainly by *hadronic* factor h_{Vp}.

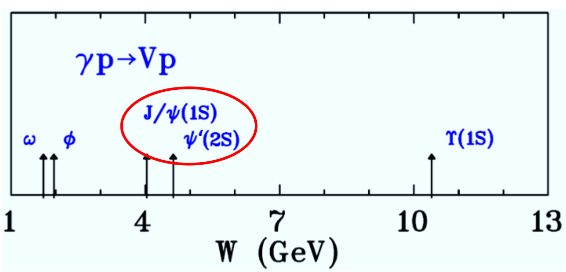
Vector Meson – Nucleon SL



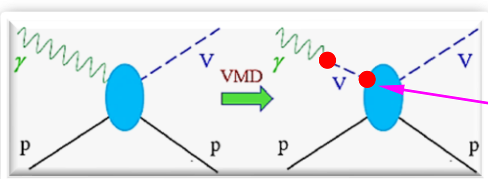
- Such big difference in *SL*s of ***Vp*** systems is determined mainly by hadronic factor h_{Vp}, & reflects strong weakening of interaction in $\bar{b}b-p$ & $\bar{c}c-p$ systems compared to that of *light* $\bar{q}q$-*p* (*q* = *u*, *d*) configurations.
- Interaction in $\bar{s}s-p$ has intermediate strength that is manifested in intermediate value of ϕp *SL*.

- Such small value of ϕp *SL* compared to typical ***hadron*** size of **1 fm**, indicates that proton is more transparent for ϕ-meson compared to ω-meson, & is much less transparent than for J/ψ-meson.

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



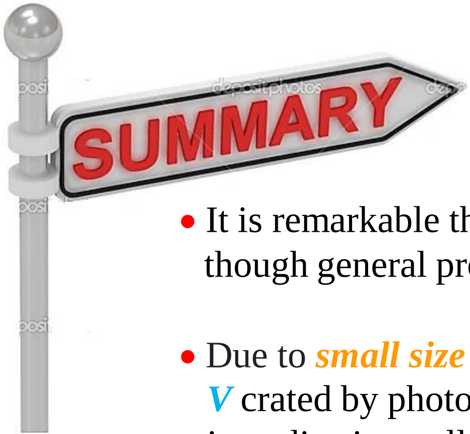
For **J/ψ**, we published two papers:
In 1st case, we used total Xsections, while in 2nd case diff Xsections. Difference has factor of **7**.
2nd case requires extrapolation to t=0 then to q=0.
One trust more result obtained using total Xsections.
a) Near threshold **s**-wave dominates & Xsection does not depend on scattering angle or **t**.
Xsections depends on **s**.
That is extrapolation in **s** looks better justified.
b) Extrapolation to t=0 covers too large interval (**δt= 2.23 GeV²**).
Too much (more than factor of **40**) with slope **b=1.67 GeV⁻²**.
We can not be sure that slope will not be changed on this large interval.



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

Courtesy of Misha Ryskin, July 2020

Outlook: A View of Future



- It is remarkable that proton is quite so *transparent* to ***J/ψ***, though general progression from ***ω*** to ***ϕ*** to ***J/ψ*** to probably **Υ** & ***ψ′***

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

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

- ***Light*** *V*s can be "*young*" as well. This depends on kinematics.
  Another point is that for slow ***heavy*** quark, one need more time to reach *equilibrium*, *i.e.*, to form final (long-living/static) ***V***.

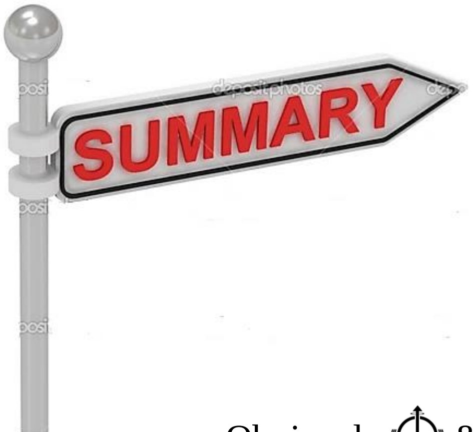
- Our phenomenology determined $\bar{q}q - p$ ***SL*** which is smaller than ***V-p SL***
  Quantitatively, there will be some difference between ***V-p SL*** & that for $\bar{q}q$ pair & ***p***.
  Or our results are low level of ***V-p SL*** determination.

- Most *theoretical* calculations using gluonic *van der Waals* interaction disagree with our *phenomenological* results. Specifically, they do not consider ***V*** *young* effect.

- This should be calculated within some *model*.
  In general, result depends on *energy, quark mass,* & *overlap integral* between $\bar{q}q$ pair *WF* & ***V*** *WF* (this put some constrain on size of $\bar{q}q$ pair).

- We found strong exponential increase of ***V-p*** *SL* with inverse mass of *V*s.

$|\alpha_{Vp}| \propto \exp(1/m_V)$

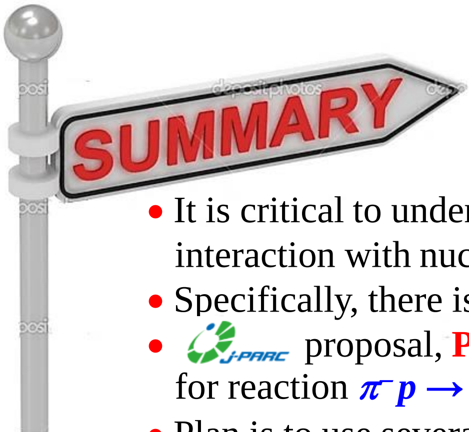


- Obviously, & facilities will open new *window* in solving the ***VN SL*** puzzle.
  It will allow to make deal with "*young*" Υ-meson as well.

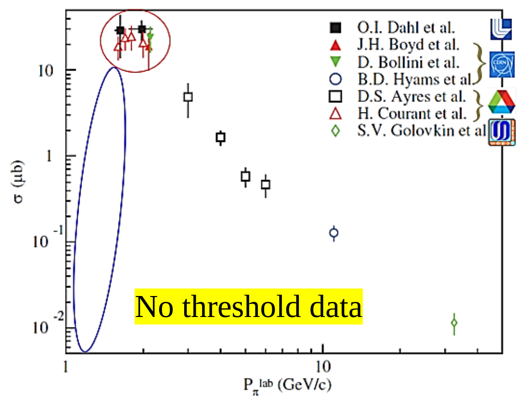
- Jefferson Lab *upgrade* will help to solve *puzzle* as well.

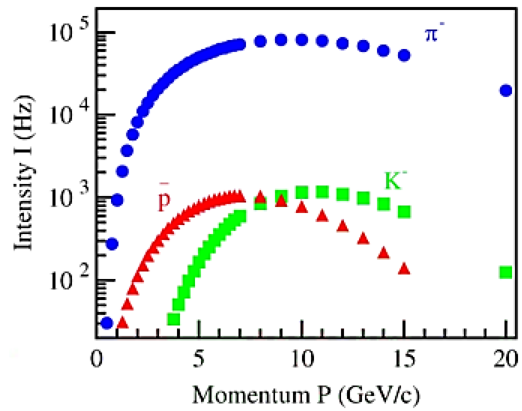
- It was observed that J/ψ-N cross section measured via J/ψ re-scattering/absorption inside nucleus is anomaly small in case of low energy photoproduction.
  This can be explained by fact that we dealt with "*young*" J/ψ of too small radius.
  Υ-photoproduction on both proton & ***nucleus*** will extend our J/ψ study.

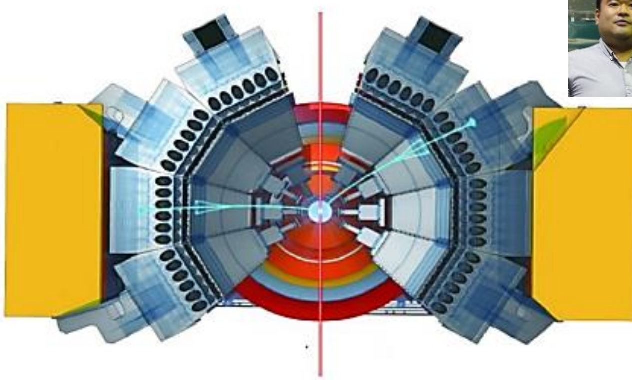
- In case of J/ψ (even Υ) ***electroproduction***, we deal with the "*young*" J/ψ (Υ) for larger Q^2
  & we will have smaller formation time & correspondingly smaller radius of heavy
  Charmonium & *Quarkonium*.

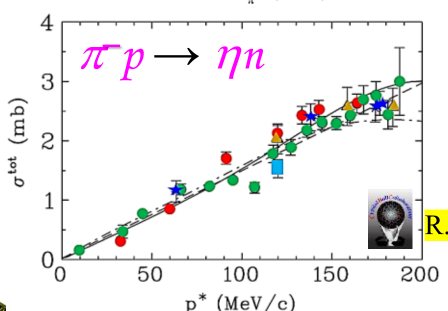


- It is critical to understand dynamics vector meson, in particular, ϕ (its mass between ω & J/ψ), interaction with nucleon @ threshold.
- Specifically, there is no effect of VMD in pion case.
- J-PARC proposal, **P95**, addressed to study *threshold* cross section measurements for reaction $\pi^- p \rightarrow \phi n$ and determine ϕN *SL*.
- Plan is to use several incident negative-pion momenta from **1.6** to **2.4** GeV/c & modified **E16** spectrometer with large acceptance for detecting K^+K^- pairs from ϕ decays.
- Let us note that there are no threshold ϕ production measurements induced by pions.
- Obviously, results of **P95** will be compared with ϕN *SL* determination using *photoproduction* of ϕ-meson data.









R.A. Arndt, W.J. Briscoe, T.W. Morrison, IS, R.L. Workman, & A.B. Gridnev, Phys Rev C **74**, 045202 (**2005**)

Do you have any questions to speaker?