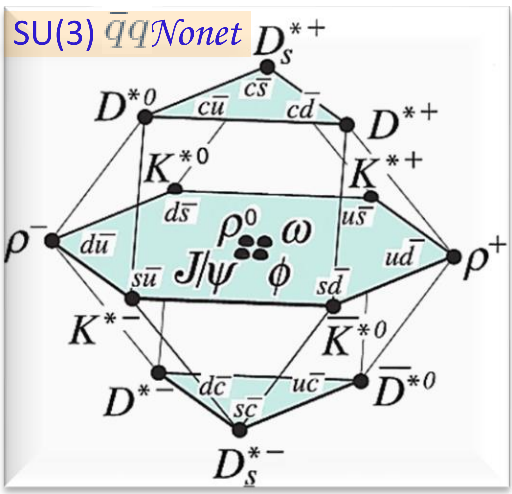
Vector Meson Domestic Zoo

- 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 SL

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

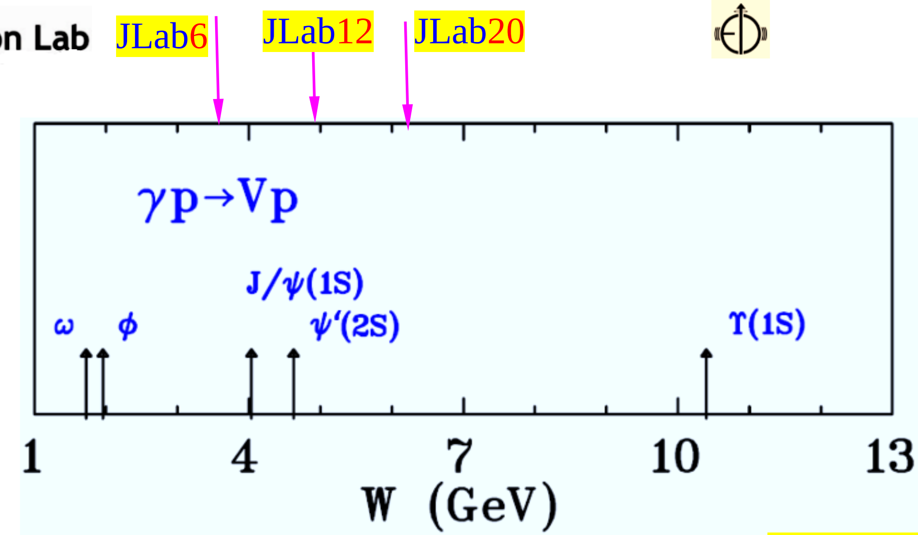
PDG

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

$$h_{Vp} = \sqrt{b_1}$$

A2 Jefferson Lab

Jefferson Lab



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)

Total Cross Sections for Vector Meson Photoproduction off Proton

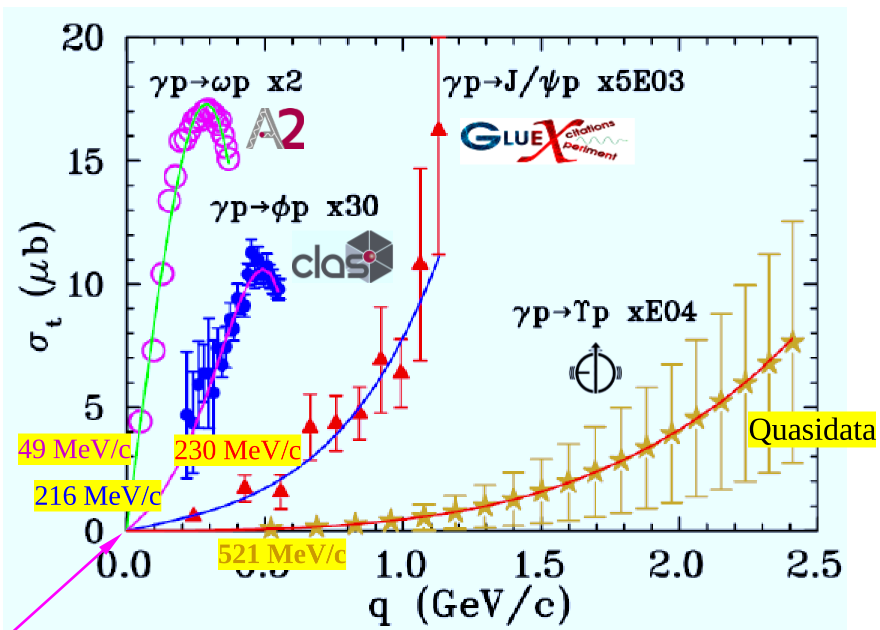
- Traditionally, σ_t behavior of near-threshold binary *inelastic* reaction

$$m_a + M_b < m_c + M_d$$

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

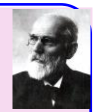
$$h_{Vp} = \sqrt{b_1}$$

as slopes (b_1) of σ_t @ threshold as function of ***q*** varies significantly from ω to ϕ to J/ψ.

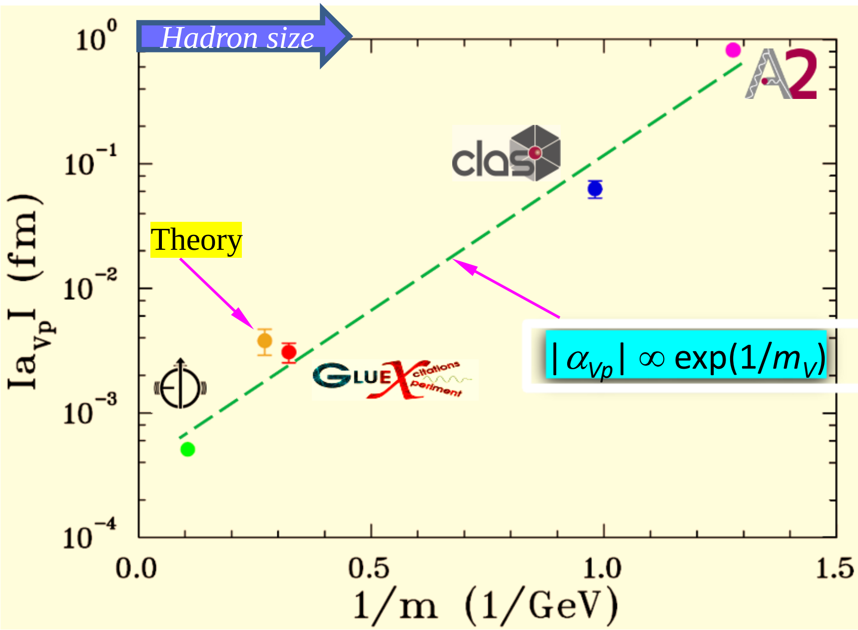
- Therefore, such big difference in *Scattering Length* is determined mainly by *hadronic* factor h_{Vp}.

Vector Meson – Nucleon SL

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

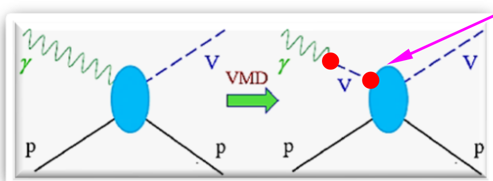


- Such big difference in *SL*s of ***Vp*** systems is determined mainly by hadronic factor h_{Vp}, & reflects strong weakening of interaction in $\bar{b}b-p$ & $\bar{c}c-p$ systems compared to that of *light* $\bar{q}q$-*p* (*q* = *u*, *d*) configurations.
- Interaction in $\bar{s}s-p$ has intermediate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



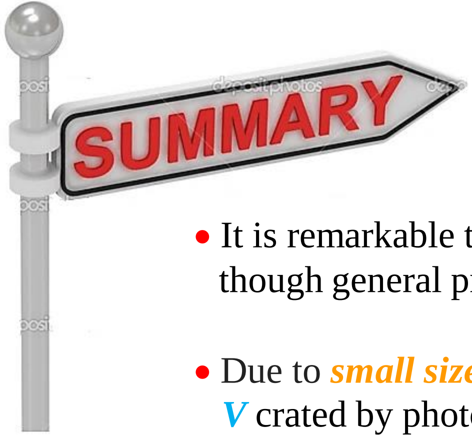
- Such small value of *ϕp SL* compared to typical ***hadron*** size of **1 fm**, indicates that proton is more transparent for *ϕ*-meson compared to *ω*-meson, & is much less transparent than for J/ψ -meson.

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



- *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



- It is remarkable that proton is quite so *transparent* to ***J/ψ***, $|\alpha_{\Upsilon p}| << |\alpha_{\psi' p}| \leq |\alpha_{J/\psi p}| << |\alpha_{\phi p}| << |\alpha_{\omega p}|$
  though general progression from ***ω*** to ***ϕ*** to ***J/ψ*** to probably **Υ** & ***ψ'***

- 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 *q-bar-q* – ***p SL*** which is smaller than ***V-p SL***
  Quantitatively, there will be some difference between ***V-p SL*** & that for *q-bar-q* pair & ***p***.
  Or our results are low level of ***Vp 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 *q-bar-q* pair WF & *V* WF
  (this put some constrain on size of ***q-bar-q*** pair).

- We found strong exponential increase of ***Vp*** *SL* with inverse mass of *V*s. $|\alpha_{Vp}| \infty \exp(1/m_V)$