# *Puzzle for the Vector Meson Threshold Photoproduction*

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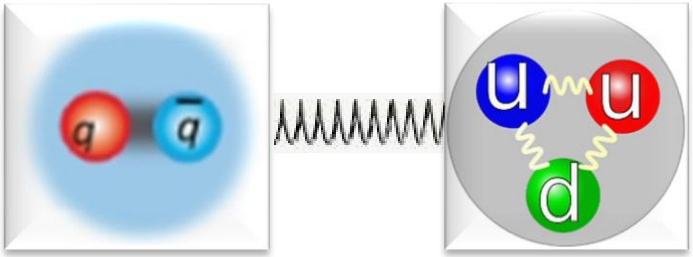
## *Outline*

- Vector Meson Nucleon Scattering Length Puzzle.
  - VMD Model.
  - CLAS & LEPS vs High Energy & LQCD Results for phi.
  - J-PARC Pion Induced Measurements.
- LHCb Pc Puzzle.
  - Does GlueX, Belle & LHCb Solve LHCb $P_c$ Puzzle?
    - Quantum Interference.
  - Alternative Solution for GlueX J/psi data & Cusp Effect.
  - J-PARC Pion Induced Measurements.
- Summary.

Supported by DE-SC0016583

# Vector Meson Nucleon Scattering Length Puzzle

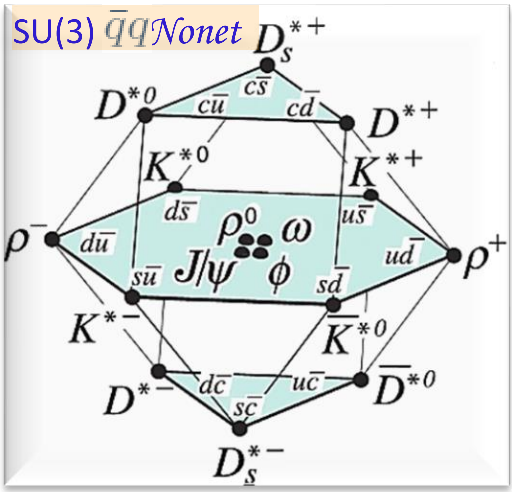


# *Vector Meson Zoo*

- 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*.

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

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







| 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 |
| $D^{*0}(2007)$ | $c\bar{u}$ | < 2.1 |
| $J/\psi(1S)(3097)$ | $c\bar{c}$ | 0.093 |
| $\psi'(2S)(3686)$ | $c\bar{c}$ | 0.284 |
| $\Upsilon(1S)(9460)$ | $b\bar{b}$ | 0.052 |

SLAC

*Open Charm*

*Charmonium*

*Quarkonium*

To avoid broad ***width*** problem @ threshold, we are not considering this case to determine **VN SL**.

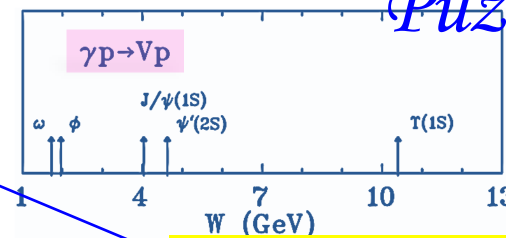
There is difference between 1S & 2S states due to `*zero*' in radial **WF**s.

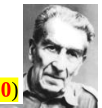
- Let us focus on **4** ***vector mesons*** from $\bar{q}q$ ***Nonet*** which widths are **narrow** enough to study *meson photoproduction* @ threshold & where data are available.

# Can Young Hypothesis Explain Vector Meson – Nucleon SL Puzzle ?

- 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.

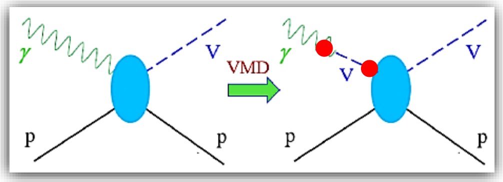
$|\alpha_{\Upsilon p}| \ll |\alpha_{J/\psi p}| \ll |\alpha_{\phi p}| \ll |\alpha_{\omega p}|$

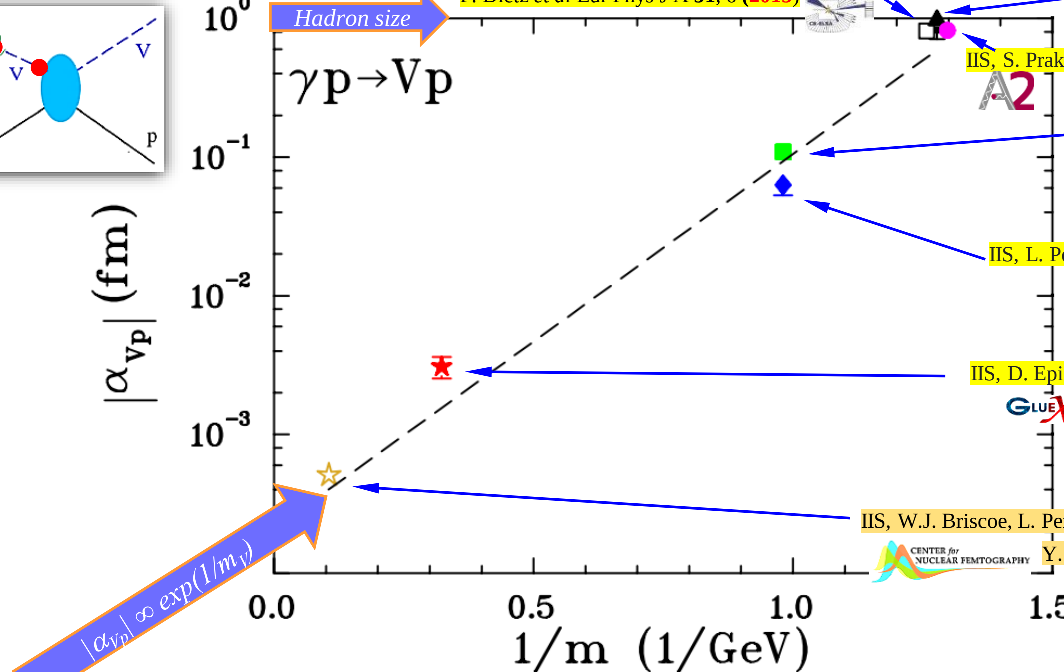


E.L. Feinberg, Sov Phys Usp, **23**, 629 (**1980**)

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**)

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

IIS, D. Epifanov, & L. Pentchev, Phys Rev C **101**, 042201 (**2020**)
A. Ali *et al*, Phys Rev Lett **123**, 072001 (**2019**)

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 $\alpha_s$ & *separation* of corresponding quarks.
- This *separation* (in *zero approximation*) is proportional to $1/m_V$.

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

***q → 0***

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

***V*** CM momentum

***Photon*** CM momentum

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

Invariant amplitude of ***V*** photoproduction

Fine-structure constant

*VMD* coupling constant, related to ***V*** ***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 do not
  - determine sign of ***SL***,
  - separate **Re** & **Im** parts of ***SL***,
  - extract *spin* **1/2** & **3/2** contributions.

# *Total Cross Sections for Vector Meson Photoproduction off Proton*

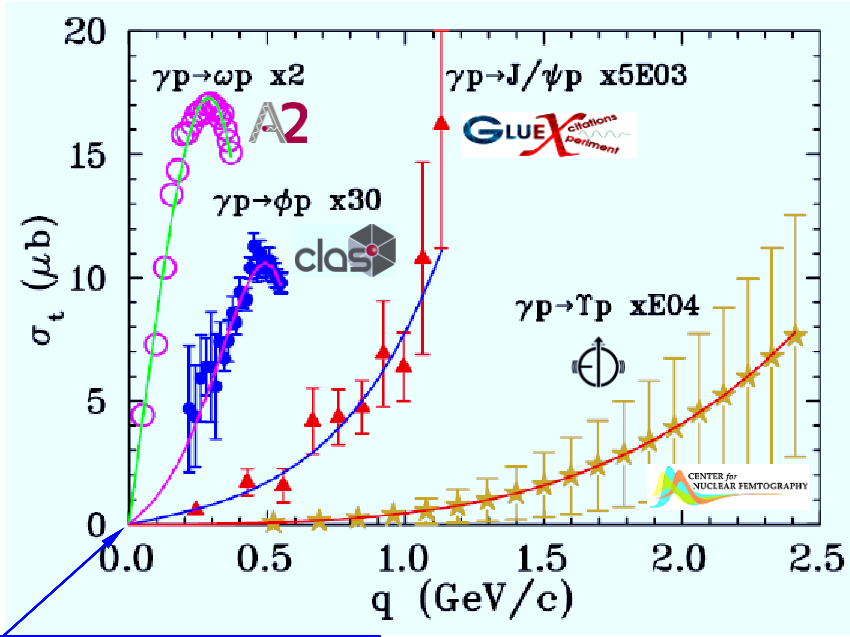
- Traditionally, $\sigma_t$ behavior of near-threshold binary *inelastic* reaction

$$m_a + M_b < m_c + M_d$$

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.



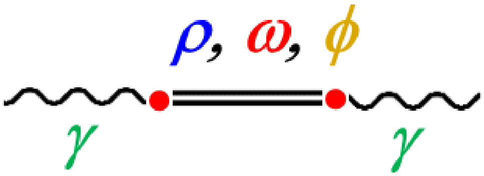

- Our ***assumption*** is that there are no ***VN bound*** states below experimental $q_{min}$.

| | |
|---|---|
| A2 | $b_1$ = (**4.42**±0.14) x $10^{-2}$ μb/(MeV/c) — IIS, 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) — IIS, L. Pentchev, & A.I. Titov, Phys Rev C **101**, 045201 (**2020**) |
| GlueX | $b_1$ = (**0.46**±0.16) x $10^{-6}$ μb/(MeV/c) — IIS, D. Epifanov, & L. Pentchev, Phys Rev C **101**, 042201 (**2020**) |
| CNF | $b_1$ = (**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 $h_{Vp} = \sqrt{b_1}$, as slopes ($b_1$) of $\sigma_t$ @ threshold as function of $q$ varies significantly from $\omega$ to $\phi$ to $J/\psi$.

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

# VMD Model



# *VMD Model*

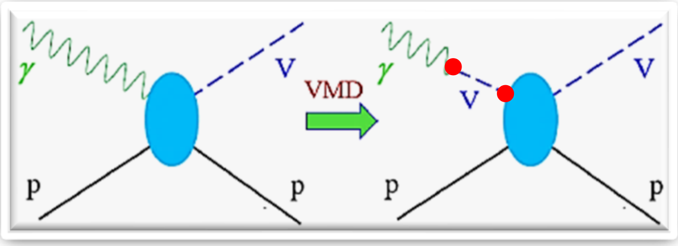
M. Gell-Mann & F. Zachariasen, Phys Rev **124**, 953 (**1961**)

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**)

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

- 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 ***V*** photoproductions @ least as first step towards their more extended theoretical studies.

# *VMD for VN Interaction*

Courtesy of Arkady Vainshtein & Misha Ryskin, July 2020

- There is no alternative *VMD* to get ***J/ψ 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 *V* final-states.]

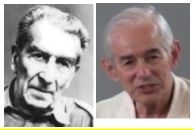
- To estimate theoretical uncertainty related to *VMD* model, one refer to estimation of cross section of ***J/ψ*** photoproduction in *peripheral model* & found strong energy dependence close to threshold because non-diagonal ***γp→Vp*** & elastic *Vp→Vp* must have larger transfer momenta vs elastic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

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

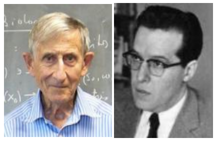
- Color factor for *charmonium* is **1**/**9** while for *open charm* is **8**/**9**.

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

- Strong suppression in *VN* interaction close to 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→Vp* scattering.



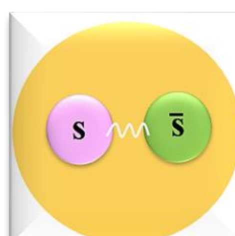
E.L. Feinberg, Sov Phys Usp, **23**, 629 (**1980**); Courtesy of Misha Ryskin, July **2020**



- 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**)

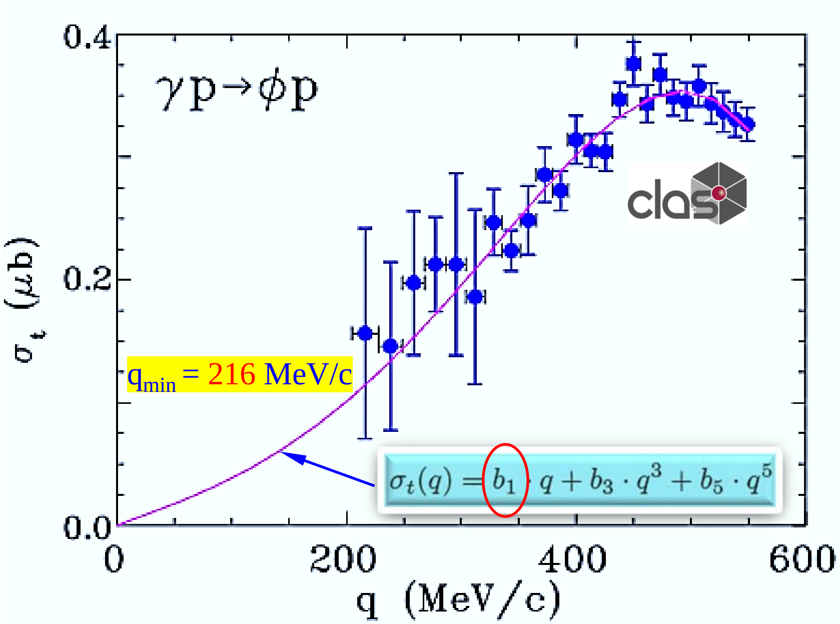
# CLAS & LEPS vs High Energy & LQCD Results for phi



# $\gamma p \to \phi p \to K^+K^-p$ *Measurements from* clas

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

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




- ***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 $\sigma_t$

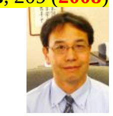
$$\sigma_t = 4\pi A_0(E_\gamma)$$

$$|\alpha_{\phi p}| = (0.063 \pm 0.010) \text{ fm}$$

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

# $\gamma d \rightarrow \phi d \rightarrow K^{+}K^{-}d$ *Forward Measurements from*

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



- Averaged scattering length $|\alpha_{\phi N}|$ of incoherent $\phi$-meson photoproduction in *deuteron* @ different $E_{\gamma}$ energies @ $t = t_{thr}$ is determined to be 0.109±0.008 fm.

C. Han, W. Kou , R. Wang, & X. Chen,  Phys Rev C **107**, 015204 (**2023**)

- Furthermore, value of $|\alpha_{\phi N}|$ as determined in this work is smaller than result 0.15 fm given from forward coherent $\phi$ -meson photoproduction from *deuterons* near threshold by Collaboration.

C. Han, W. Kou , R. Wang, & X. Chen,  Phys Rev C **107**, 015204 (**2023**)

# *Van der Waals Potential for $\phi N$ SL*

- One can estimate $|\alpha_{\phi N}|$ using $\phi N$ potential approaches for analysis of $\phi$-nucleus bound states.

- H. Gao, T.S.H. Lee, & V. Marinov, Phys Rev C **63**, 022201 (**2001**) suggested using QCD **van der Waals** *attractive* $\phi N$ *pot*.

- This potential reads $V_{\phi N} = -A \exp(-\mu r)/r,$ where A = 1.25 & $\mu$ = 0.6 GeV.

- Corresponding ***SL***, $|\alpha_{\phi N}| \simeq 2.37$ fm, found by direct solution of **Schrödinger** *equation*, leads to large cross section $d\sigma/dt \simeq 160\ \mu b/GeV^2$.
  It is more than *two orders of magnitude* greater than experimental hint & provides problem for this potential model.

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

# *Experimental Evidence for Attractive $p\phi$ Interaction from*

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

- Recently, Collaboration has deduced spin averaged **SL**

$$a_{\phi N} = (0.85 \pm 0.34 \pm 0.14) + i\,(0.16 \pm 0.10 \pm 0.09)\ \text{fm}$$

from two-particle momentum correlation function using *Lednicky-Lyuboshits* approach

R. Lednicky & V.L. Lyuboshits, Sov J Nucl Phys **35**, 770 (**1982**)


- Actually, is doing *two-particle correlations* of combined $p\phi$ & $\bar{p}\phi$ pairs measured in *high-multiplicity* in ***pp*** collisions at W = **13** TeV.
- Besides, FSI correlation **C**(**k**) depends on production mechanism.
- Then, assumes that *proton* & $\phi$ are produced *independently* @ ~**1** fm distance.
- Another problem is that it is practically impossible to observe $p\phi$ (or any *vector meson*) correlation (@ very small $p\phi$ energy, *i.e.*, *near threshold*) @ (with or another detector).

# *Attractive* $N\phi$ *Interaction from* HAL (Hadrons to Atomic nuclei from Lattice QCD)

- Using (2 + 1)-flavor lattice QCD simulations with nearly physical quark masses, HAL has simulated $\phi N$ scattering process for spin **3/2** channel

$$a_{\phi N}^{(3/2)} = \overset{?}{-}1.43 \pm 0.23^{+0.36}_{-0.06}\ \text{fm}$$

Y. Lyu *et al* Phys Rev D **106**, 074507 (**2022**)

- Instead of $\phi$ photoproduction process, they simulated $\phi N$ elastic scattering reaction.

  - Note, however, that in case of photoproduction, we deal not with completely formatted $\phi$ meson but with $s\bar{s}$ pair which only @ end will form $\phi$ meson.
    Amplitude of this pair interaction with nucleon may be not exactly equal to that for $\phi N$ amplitude.
    Long ago this was called "***young***" effect.

- $\phi N$ system is assumed as "on lattice" and this result is but "numerical experiment."

- Using lattice calculations for spin **3/2** $\phi N$ interaction by HAL are used to constrain spin **1/2** counterpart from fit of experimental $\phi p$ correlation function measured by ALICE.

- Corresponding **SL** is

$$a_{\phi N}^{(1/2)} = \overset{?}{-}\left(1.54^{+0.53}_{-0.53}(stat)^{+0.16}_{-0.09}(syst)\right) + \ i\ \left(0.\overset{?}{0}0^{+0.35}_{-0.00}(stat)^{+0.16}_{-0.00}(syst)\right)\ \text{fm}$$

E. Chizzali *et al* Phys Lett B **848**,138358 (**2024**)

- Absolute *SL* value by HAL agreed with ALICE while sign is different.

- See comments above.

# *Attractive* *Nϕ* *Interaction* *from*

- The vector meson-baryon interaction in a coupled channel scheme is revisited within the correlation function framework. As illustrative cases to reveal the important role played by the coupled channels, we focus on the $\phi$p and $\rho^0$p systems given their complex dynamics and the presence of quasi-bound states or resonances in the vicinity of their thresholds. We show that the $\phi$p femtoscopic data provide novel information about a $N^*$ state present in the experimental region and anticipate the relevance of a future $\rho^0$p correlation function measurement in order to pin down the $S = 0$, $Q = +1$ vector meson-baryon interaction as well as to disclose the characterizing features of the $N^*(1700)$ state.

?

| (fm) | Pure theoretical | Bootstrap |
|---|---|---|
| $a_0^{\phi p}$ | $0.272 + i\,0.189$ | $(-0.034 \pm 0.035) + i\,(0.57 \pm 0.09)$ |

A. Feijooa, M. Korwiesera, L. Fabbietti, arXiv:2407.01128 [hep-ph]

Re*SL* ~ Im*SL*     Re*SL* << Im*SL*

- The existence of a bound state of a $\phi$ meson and proton has been recently indicated on the basis of a combined analysis of the measured $\phi$-$p$ correlation function and the QCD lattice calculations of $\phi$-$p$ interaction in the spin 1/2 and 3/2 channels. We check whether the correlation functions and bound state formation rate satisfy the sum rule which follows from the completeness of quantum states. The sum rule is not satisfied but it is close to it, suggesting that the inferred scattering parameters, which determine the correlation functions, are not fully consistent with the potential responsible for the bound state existence.

| | $\Re a$ [fm] | $\Im a$ [fm] |
|---|---|---|
| $s = \frac{1}{2}$ | ? $1.54^{+0.62}_{-0.69}$ | $0.00^{+0.00}_{-0.51}$ |
| $s = \frac{3}{2}$ | $-1.43^{+0.59}_{-0.29}$ | 0 |

A. Kuros , R. Maj, & S. Mrowczynski, arXiv:2408.11941 [hep-ph]

- Of course, to account for coupling channels is a good idea.
  - Not sure this will be important near thr (*i.e.*, for *SL*)
  - Sure, ***femtoscopic data*** is not sufficiently precise to provide new information for *SL* (besides this ***femtoscopic data*** is affected by many other effects)

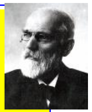
- There are too many different effects which affect final result but are not under good control.
- Let me recall that ``source radius'' depends on multiplicity of particular event, the mean $k_t$ of $\pi\pi$ pair & some other variables.
- Most probably radius of event with $p\phi$ production is NOT equal to that measured via average $\pi\pi$ **Bose-Einstein** correlations.

V.A. Schegelsky & M.G. Ryskin, arXiv:1608.05218 [hep-ph], arXiv:1604.01189 [hep-ph], [arXiv:1506.03718 [hep-ph].

# *Revisited Vp Scattering Length*

- 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*.



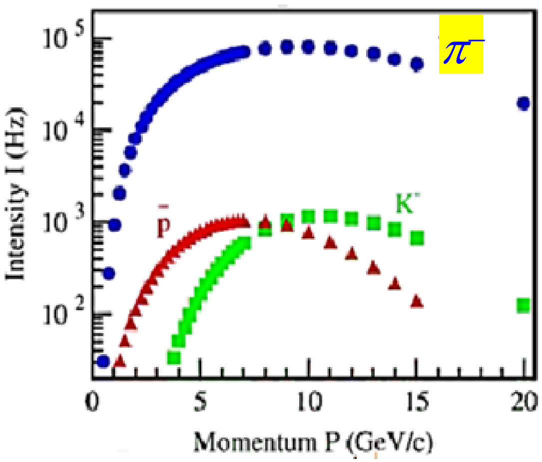
Courtesy of Yuri Dokshitzer, **2023**

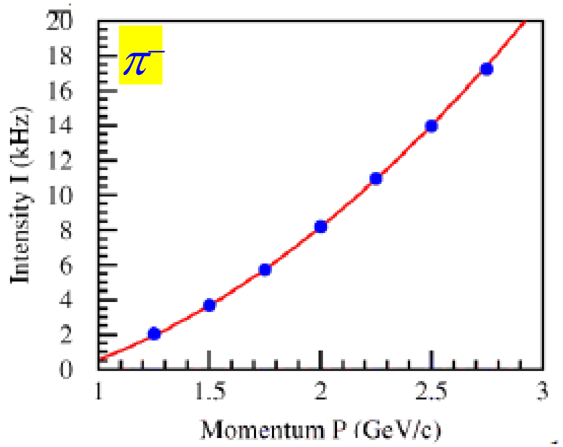
# J-PARC Pion Induced Measurements

# J-PARC for $\pi^- p \to \phi\, p$

*E45* Proposal, J-PARC, 2024

- *E45* may help to solve puzzle of $\phi$N SL.

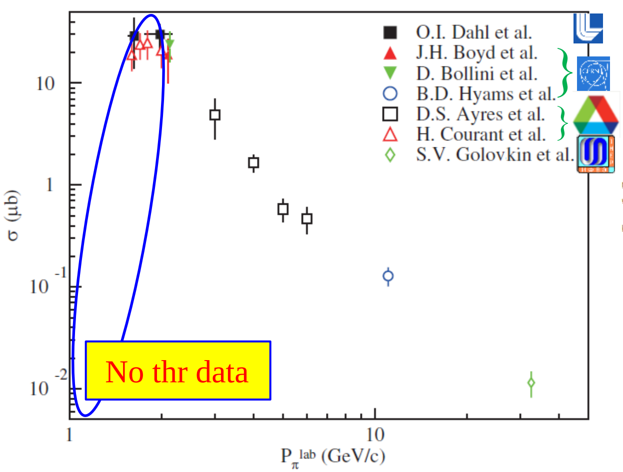


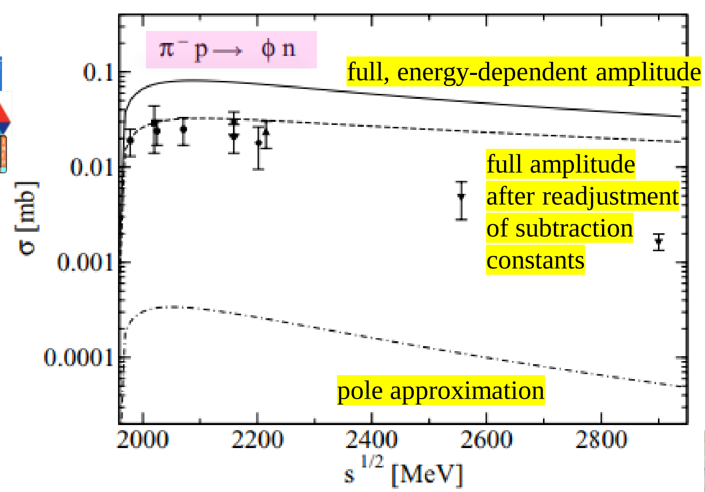




- There are no $\phi$ beams to do $\phi$ n→$\phi$ n.
- Obviously, $\pi^-$p→$\phi$ n *DB* is limited.
- No data @ *threshold*.

- Dynamics in $\pi^-$p→$\phi$ n reaction is different *vs* $\gamma$ p→$\phi$ p.
- Moreover, in $\pi^-$p→$\phi$ n case, $\phi$-meson can be formed from admixture of $\bar{s}s$ pair in proton wave function.

- Additionally, $\phi$-meson production using pion beam is *inelastic* reaction & determination of $\phi$N *SL* requires some assumptions (no *VMD*).
- For the $\pi$N *SL* (*elastic* case), there is recipe in "*Höhler's Bible*".




G. Hoehler, *Pion–Nucleon Scattering*, Landoldt–Boernstein, edited by H. Schopper (Springer, New York, **1983**), Vol. **I/9b2.**

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

# *Phenomenology for SL from* $\pi^- p \to \phi\, p$ & $\pi^- p \to J/\psi\, p$

R.A. Arndt, W.J. Briscoe, T.W. Morrison, IIS, R.L. Workman, & A. Gridnev, Phys Rev C **72**, 045202 (**2005**)

- Data for $\pi^- p \to \phi\, p$ can be described very well by ***linear fit*** (dashed line).
- This is because of **S**-wave *dominance* of total Xsec.
- From *slope* of *best-fit line*, restriction on imaginary part of *ηN elastic scattering amplitude* $A_{\eta N}$ can be found.

- Optical theorem leads to

$$ImA_{\eta N} = p_\eta / 4\pi\ \sigma(\eta n)^{tot}$$
$$= p_\eta / 4\pi\ [\sigma(\eta n\to\pi N) + \sigma(\eta n\to 2\pi N) + \sigma(\eta n\to\eta N)]$$
$$= 3p_\pi / 8\pi\ p_\eta^2\ \sigma(\pi^- p\to\eta n) + p_\eta / 4\pi\ [\sigma(\eta n\to 2\pi N) + \sigma(\eta n\to\eta N)]$$

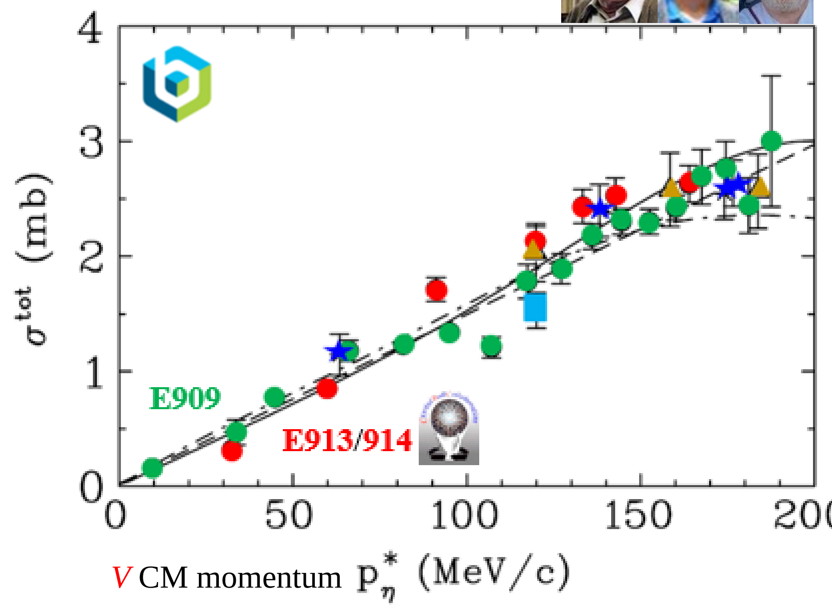
- As a result, we have

$$ImA_{\eta N} \geq 3p_\pi / 8\pi\ p_\eta\ \sigma(\pi^- p\to\eta n)$$

- Using ***linear fit***, E909 thr data give

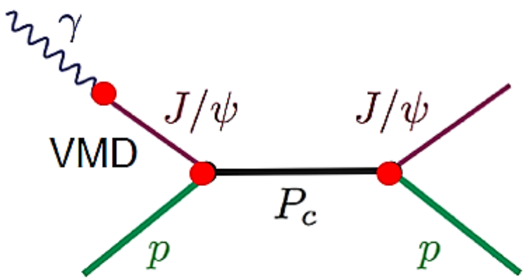
$$1/\ p_\eta\ \sigma(\pi^- p\to\eta n) = 15.2 \pm 0.8\ \mu b/MeV$$

$$ImA_{\eta N} \geq 0.172 \pm 0.009\ \text{fm}$$




- PWA: $ReA_{\eta N} > ImA_{\eta N}$ right near threshold.

# LHCb Pc Puzzle



# *Narrow Pentaquarks from* $\Lambda_b \to P_c K^- \to (J/\psi p) K^-$

- QCD gives rise to *hadron spectrum*.

Volume 8, number 3 PHYSICS LETTERS 1 February 1964

A SCHEMATIC MODEL OF BARYONS AND MESONS

M. GELL-MANN

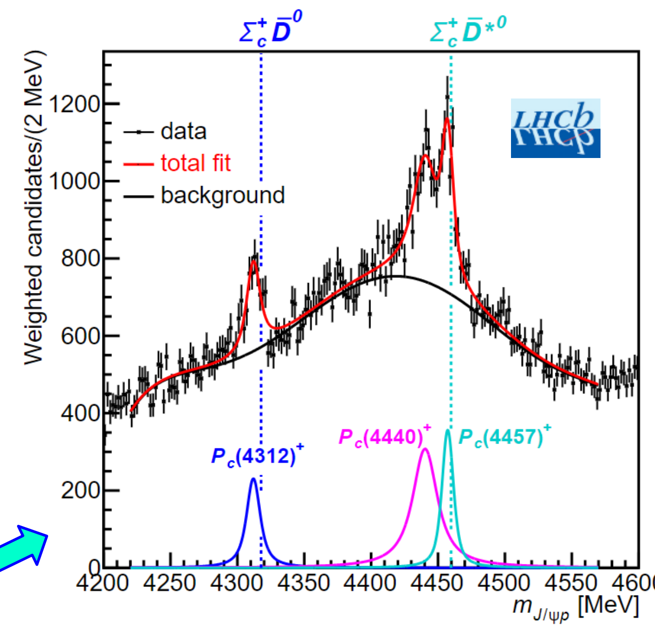
If we assume that the strong interactions of baryons and mesons are correctly described in terms of the broken "eightfold way" ... Baryons can now be constructed from quarks by using the combinations $(qqq)$, $(qqqq\bar{q})$, etc., while mesons are made out of $(q\bar{q})$, $(qq\bar{q}\bar{q})$, etc.

- Many $\bar{q}q$ & $qqq$ states have been *observed*.

PDG 220 & 100.

- $\bar{q}q\bar{q}q$, $qqq$ $\bar{q}q$… *are not forbidden* or we *do not know* it yet.

- LHCb claims *evidence* for ***four*** *hidden-charm* $qqq\bar{q}q$ *states* near *open-charm* decay thresholds for $\Sigma_c^+\bar{D}^0$ & $\Sigma_c^+\bar{D}^{*0}$ in $\Lambda_b \to P_c K^- \to (J/\psi\, p) K^-$ decays.



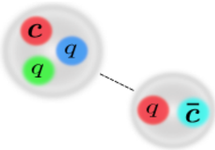

R. Aaij *et al*, Phys Rev Lett **122**, 222001 (2019)
R. Aaij *et al*, Phys Rev Lett **115**, 072001 (2015)

- Bump *hunting*:
  - no *quantum numbers*
  - no *pole positions*

| State PDG | Mass (MeV) | $\Gamma[P_{c\bar{c}} \to J/\psi p]$ (MeV) | Significance ($\sigma$) |
|---|---|---|---|
| $P_{c\bar{c}}(4312)^+$ | $4311.9 \pm 0.7^{+6.8}_{-0.6}$ | $9.8 \pm 2.7^{+3.7}_{-4.5}$ | 7.3 |
| $P_{c\bar{c}}(4380)^+$ | $4380 \pm 8 \pm 29$ | $205 \pm 18 \pm 86$ | ... |
| $P_{c\bar{c}}(4440)^+$ | $4440.3 \pm 1.3^{+4.1}_{-4.7}$ | $20.6 \pm 4.9^{+8.7}_{-10.1}$ | 5.4 |
| $P_{c\bar{c}}(4457)^+$ | $4457.3 \pm 0.6^{+4.1}_{-1.7}$ | $6.4 \pm 2.0^{+5.7}_{-1.9}$ | 5.4 |

# *Interpretation of $\mathcal{P}_c(4312)^+$*

- Interpretation of $P_c(4312)^+$ is consistent with




- *Molecules* $\bar{D}^{(*)}\Lambda_c$ & $\bar{D}^{(*)}\Sigma_c^{(*)}$ coupled to *hidden charm* $5q$.

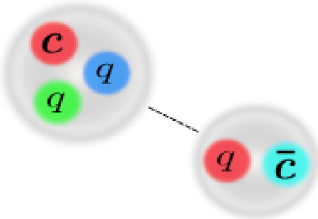
Y. Yamaguchi, A. Hosaka, S. Takeuchi, & M. Takizawa, J Phys G **47**, 053001 (**2020**)
M.I. Eides & V.Yu. Petrov, Phys Rev D **98**, 114037 (**2018**)
Y. Yamaguchi, A. Giachino, A. Hosaka, E. Santopinto, S. Takeuchi, & M. Takizawa, Phys Rev D **96**, 114031 (**2017**)

- Possibility of *compact bound state*.

IIS, W.J. Briscoe, E. Chudakov, I. Larin, L. Pentchev, A. Schmidt, & R.L. Workman, Phys Rev C **108**, 015202 (**2023**)
Z. Zhang, J. Liu, J. Hu, Q. Wang, & U.-G. Meißner, Science Bulletin **68**, 981 (**2023**)
X.-W. Wang, Z.-G. Wang, G.-L. Yu, & Q. Xin, Sci. China Phys Mech Astron **65**, 291011 (**2022**)
M.I. Eides, V.Y. Petrov, & M.V. Polyakov, Mod Phys Lett A **35**, 2050151 (**2020**)

- *Pole structure* of $\mathbf{P_c(4312)^+}$ & uniformized ***S**-matrix*.

D. Winney *et al*, Phys Rev D **108**, 5 (**2023**)
L.M. Santos, V.A.A. Chavez, & D.L. Sombillo, arXiv:**2405**.11906 [hep-ph]



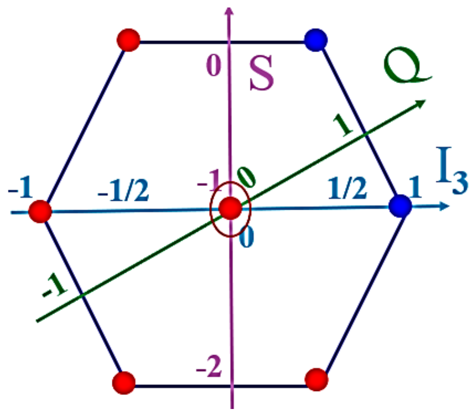

# SU(3) Multiplets

Assumed to be Meson-Baryon Molecules

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

**1** — $P^{0}_{cs}(4337)$ — $\bar{D}^{(*)}\Sigma_c^{(*)}$, $\bar{D}_s^{(*)}\Lambda_c$ → ?

**8**



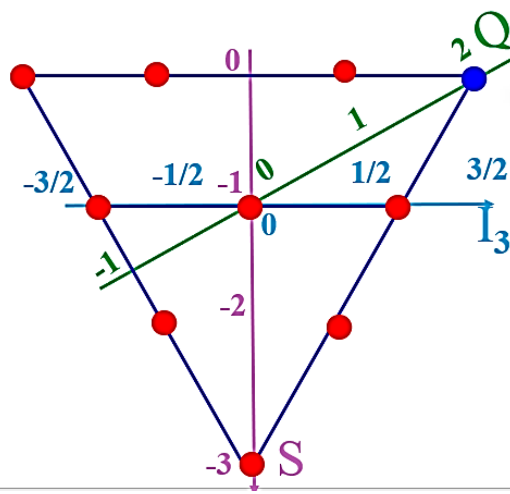

$P^{1/2}_{c}(4440)$ — $\bar{D}^{(*)}\Lambda$, $\bar{D}^{(*)}\Sigma_c^{(*)}$

$P^{0}_{cs}(4457)$ — $\bar{D}^{(*)}\Sigma_c^{(*)}$, $\bar{D}^{(*)}\Sigma'_c$, $\bar{D}_s^{(*)}\Sigma_c^{(*)}$

$P^{1}_{cs}$

$P^{1/2}_{css}$ — $\bar{D}_s^{(*)}\Sigma_c^{(*)}$, $\bar{D}_s^{(*)}\Sigma'_c$

**10**




$P^{3/2}_{c}(4312)$ — $\bar{D}^{(*)}\Sigma_c^{(*)}$

$P^{1}_{cs}$

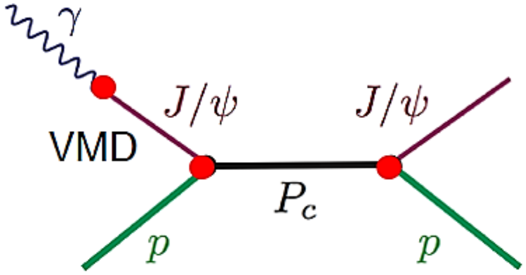
$P^{1/2}_{css}$

$P^{0}_{csss}$

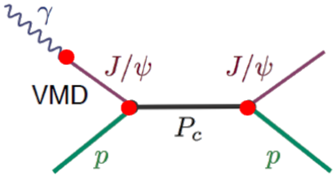
In $D^{(*)}$, parentheses mean that there are ***two*** spin states **D** & **D***

Courtesy of Atsushi Hosaka, **2024**

# Does GlueX, Belle, & LHCb Solve LHCb Pc Puzzle?



# How Bump Hunting works in 2019-23 GlueX data ?

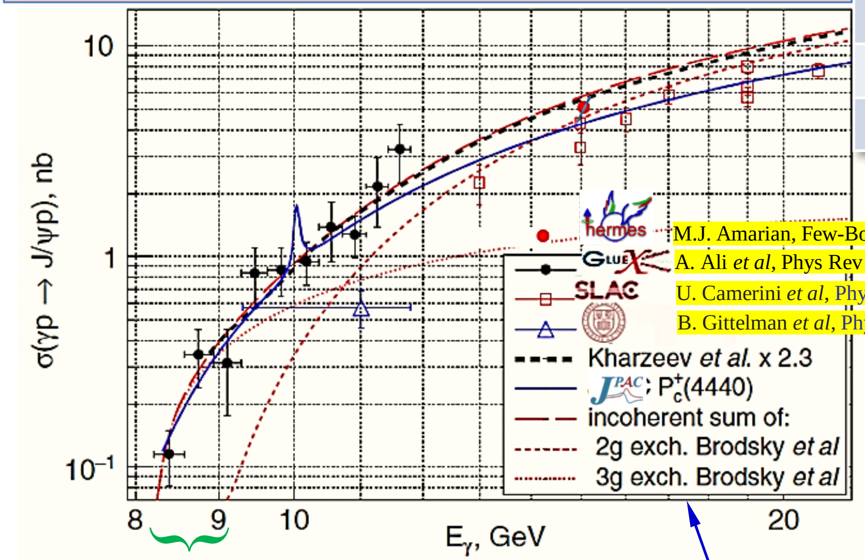



- GlueX sees *no evidence* for LHCb $P_c$s Upper limits @ 90% CL

A. Ali *et al*, Phys Rev Lett **123**, 072001 (**2019**)
S. Adhikari *et al*, Phys Rev C **108**, 025201 (**2023**)

**2016–2017** data: **469**±22 $\gamma p \to J/\psi p \to e^+e^- p$ & **68** pb$^{-1}$

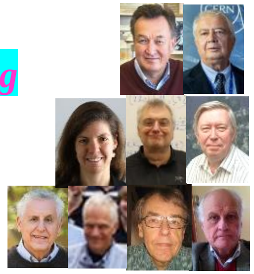
| State | Upper Limit |
|---|---|
| $P_c(4312)$ | **4.6** % |
| $P_c(4440)$ | **2.3** % |
| $P_c(4457)$ | **3.8** % |



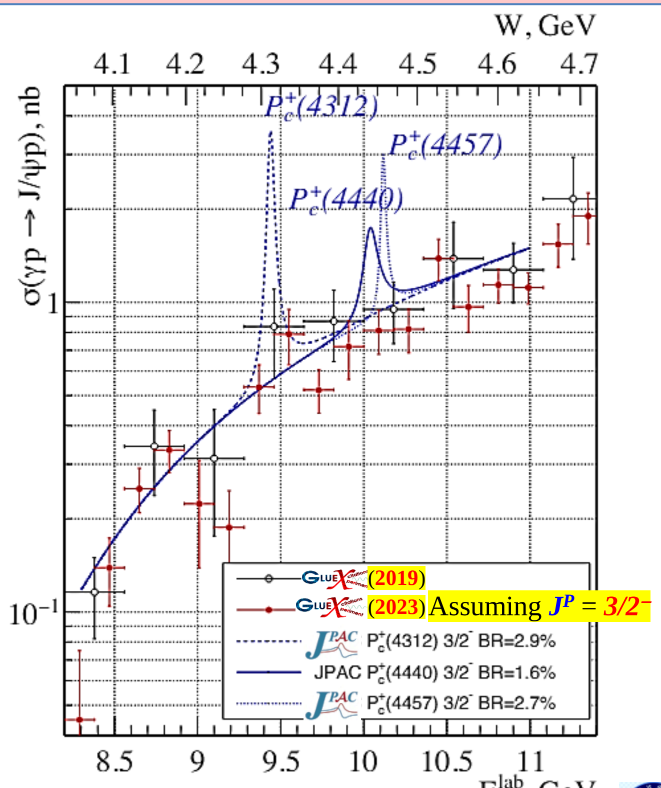

M.J. Amarian, Few-Body Syst Suppl. **11**, 359 (**1999**)
A. Ali *et al*, Phys Rev Lett **123**, 072001 (**2019**)
U. Camerini *et al*, Phys Rev Lett **35**, 483 (**1975**)
B. Gittelman *et al*, Phys Rev Lett **35**, 1616 (**1975**)

D. Kharzeev, H. Satz, A. Syamtomov, & G. Zinovjev, Nucl Phys A **661**, 568 (**1999**)
JPAC A.N. Hiller Blin *et al*, Phys Rev D **94**, 034002 (**2016**)
S. Brodsky, E. Chudakov, P. Hoyer, & J.M. Laget, Phys Lett B **498**, 23 (**2001**)

- Near *threshold*, ***3g*** works better than *2g*



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

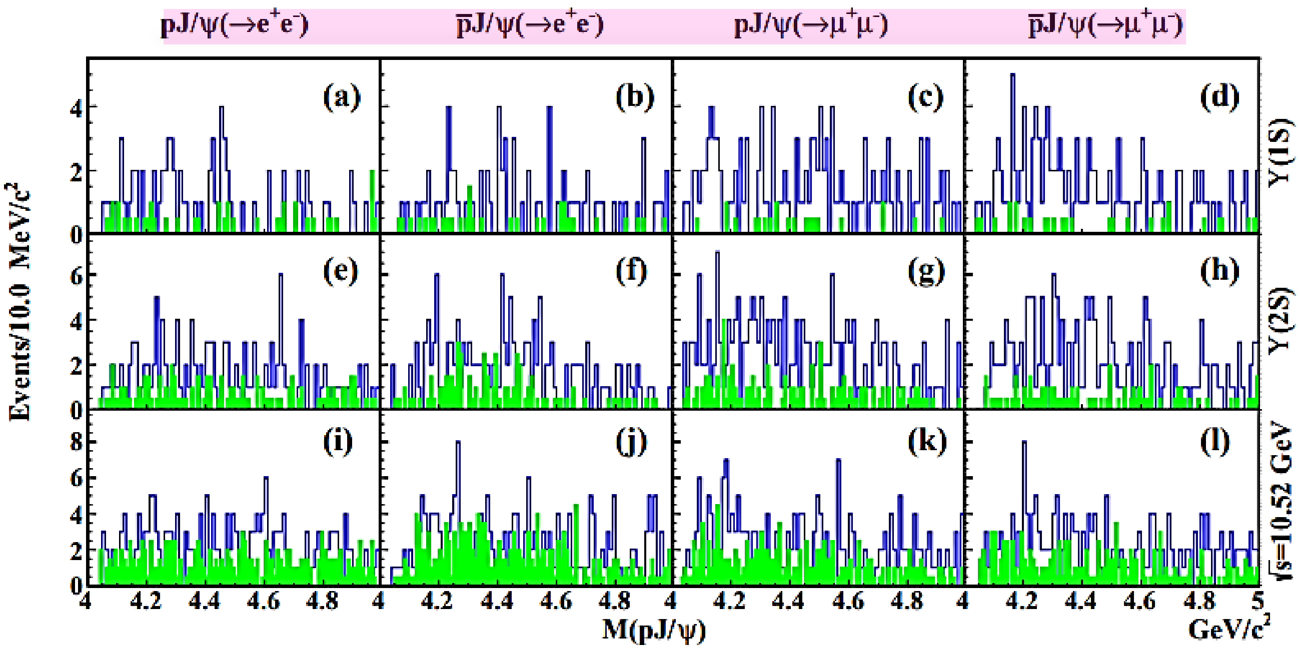


# *Search for Pentaquark State Decaying into $pJ/\psi$ in $\Upsilon(1S, 2S)$ Inclusive Decays @ BELLE*

X. Dong *et al* arXiv:2403.04340 [hep-ex]

*Bump Hunting*

- Using the data samples of 102 million $\Upsilon(1S)$ and 158 million $\Upsilon(2S)$ events collected by the Belle detector, we search for a pentaquark state in the $pJ/\psi$ final state from $\Upsilon(1,2S)$ inclusive decays. Here, the charge-conjugate $\bar{p}J/\psi$ is included. We observe clear $pJ/\psi$ production in $\Upsilon(1,2S)$ decays and measure the branching fractions to be $\mathcal{B}[\Upsilon(1S) \to pJ/\psi + anything] = [4.27 \pm 0.16(stat.) \pm 0.20(syst.)] \times 10^{-5}$ and $\mathcal{B}[\Upsilon(2S) \to pJ/\psi + anything] = [3.59 \pm 0.14(stat.) \pm 0.16(syst.)] \times 10^{-5}$. We also measure the cross section of inclusive $pJ/\psi$ production in $e^+e^-$ annihilation to be $\sigma(e^+e^- \to pJ/\psi + anything) = [57.5 \pm 2.1(stat.) \pm 2.5(syst.)]$ fb at $\sqrt{s} = 10.52$ GeV using an 89.5 fb$^{-1}$ continuum data sample. There is no significant $P_c(4312)^+$, $P_c(4440)^+$ or $P_c(4457)^+$ signal found in the $pJ/\psi$ final states in $\Upsilon(1,2S)$ inclusive decays. We determine the upper limits of $\mathcal{B}[\Upsilon(1,2S) \to P_c^+ + anything] \cdot \mathcal{B}(P_c^+ \to pJ/\psi)$ to be at the $10^{-6}$ level.



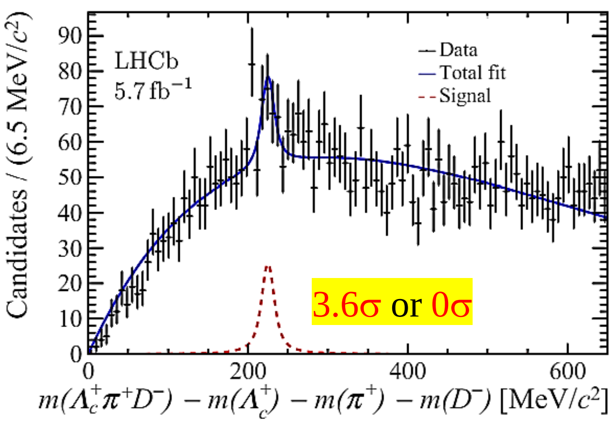

- Xsec is *too small* to make solid conclusion.
- *High Statistics* is not sufficient to convince.
- Let me do not discuss how *good* these reactions to look for $P_c$s…

# *Search for Pentaquark State in Charm Hadron Final State @ LHCb*

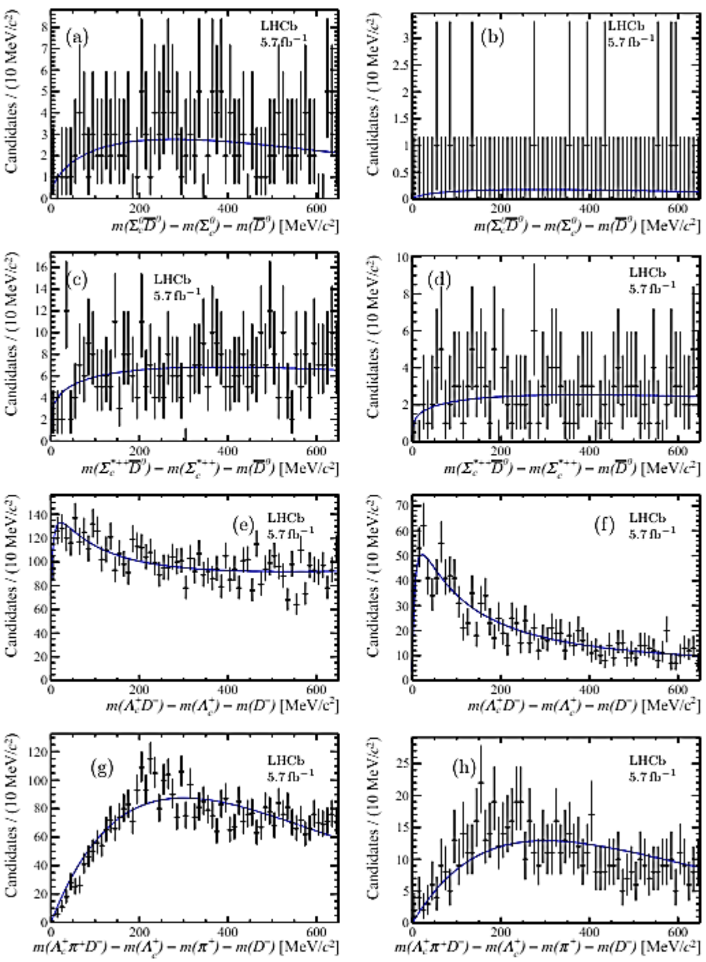
R. Arij *et al* Phys Rev D **110**, 032001 (**2024**)

*Bump Hunting*

- A search for hidden-charm pentaquark states decaying to a range of $\Sigma_c\overline{D}$ and $\Lambda_c^+\overline{D}$ final states, as well as doubly-charmed pentaquark states to $\Sigma_c D$ and $\Lambda_c^+ D$, is made using samples of proton-proton collision data corresponding to an integrated luminosity of $5.7\,\mathrm{fb}^{-1}$ recorded by the LHCb detector at $\sqrt{s} = 13\,\mathrm{TeV}$. Since no significant signals are found, upper limits are set on the pentaquark yields relative to that of the $\Lambda_c^+$ baryon in the $\Lambda_c^+ \to pK^-\pi^+$ decay mode. The known pentaquark states are also investigated, and their signal yields are found to be consistent with zero in all cases.




Best case



## *Revisited* LHCb *Results*

*Bump Hunting*

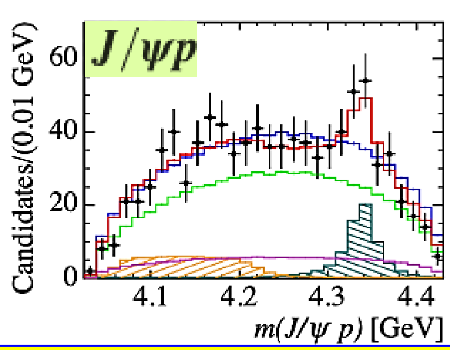
- I do not think these *negative* results *may* *``kill'' hidden charm states*.
- Point is that we do not know theoretically expected **Xsec** / BR.
- Now, these results are just some ***additional constraints*** on pentaquark model.

# *Search for Pentaquark State in $J/\psi p$ & $J/\psi \bar{p}$ in $B^0_s \to J/\psi p \bar{p}$ Decays*

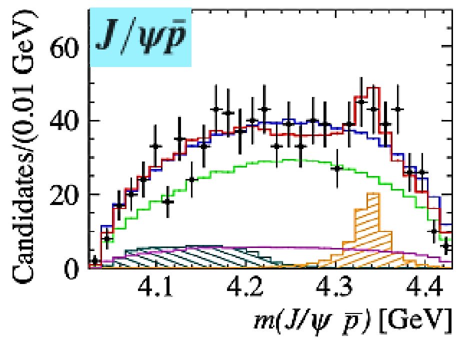
# *Observation of $J/\psi\Lambda$ Res Consistent with Strange 5q Candidate in $B^- \to J/\psi \Lambda \bar{p}$ Decay*

*Bump Hunting*

- An amplitude analysis of flavor-untagged $B^0_s \to J/\psi p \bar{p}$ decays is performed using a sample of $797 \pm 31$ decays reconstructed with the LHCb detector. The data, collected in proton-proton collisions between 2011 and 2018, correspond to an integrated luminosity of 9 $\text{fb}^{-1}$. Evidence for a new structure in the $J/\psi p$ and $J/\psi \bar{p}$ systems with a mass of $4337^{+7}_{-4}\,^{+2}_{-2}$ MeV and a width of $29^{+26}_{-12}\,^{+14}_{-14}$ MeV is found, where the first uncertainty is statistical and the second systematic, with a significance in the range of 3.1 to 3.7$\sigma$, depending on the assigned $J^P$ hypothesis.



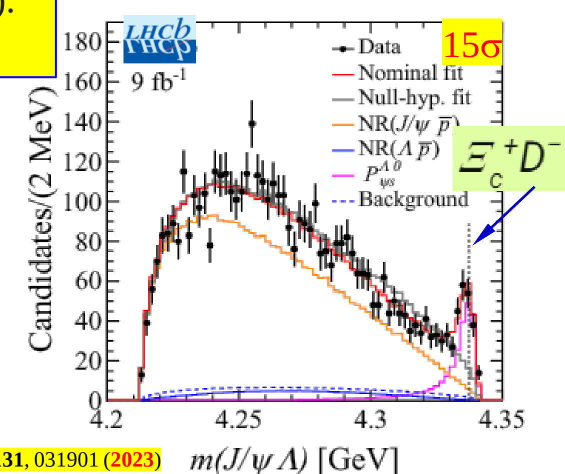

3.1σ to 3.7σ




R. Arij *et al* Phys Rev Lett **128**, 062001 (2022)

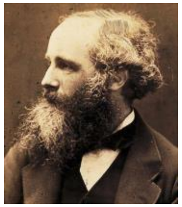
- They claim that mass resolution is much better than 10 MeV (4337-4312 = 25 MeV).
- However, one can *exclude* that P(4337) is the same as P(4312).

- An amplitude analysis of $B^- \to J/\psi \Lambda \bar{p}$ decays is performed using 4400 signal candidates selected on a data sample of $pp$ collisions recorded at center-of-mass energies of 7, 8, and 13 TeV with the LHCb detector, corresponding to an integrated luminosity of 9 $\text{fb}^{-1}$. A narrow resonance in the $J/\psi\Lambda$ system, consistent with a pentaquark candidate with strangeness, is observed with high significance. The mass and the width of this new state are measured to be $4338.2 \pm 0.7 \pm 0.4$ MeV and $7.0 \pm 1.2 \pm 1.3$ MeV, where the first uncertainty is statistical and the second systematic. The spin is determined to be 1/2 and negative parity is preferred. Because of the small $Q$-value of the reaction, the most precise single measurement of the $B^-$ mass to date, $5279.44 \pm 0.05 \pm 0.07$ MeV, is obtained.



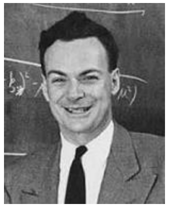

R. Arij *et al* Phys Rev Lett **131**, 031901 (2023)

# Quantum Interference



*When looking at Maxwell equations,*
*it is hard to imagine how beautiful the rainbow is.*

*Richard Feynman*



Similar may be said about *Quantum Interference*.

*Everybody knows that the interference does exist.*
*But it is not always easy to imagine*
*how it will work in a particular case.*

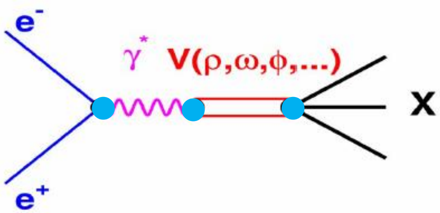
*Yakov Azimov*

# *Interference from* SND

Ya. Azimov, J Phys G **37**, 023001 (**2010**)

PDG: $\Gamma(\rho^0)$ = 149.4 MeV; $\Gamma(\omega)$ = 8.5 MeV; $\Gamma(\phi)$ = 4.3 MeV

$\Gamma(\rho^0 \to 3\pi)$ = 0.015 MeV Isospin violated
$\Gamma(\omega \to 3\pi)$ = 7.58 MeV
$\Gamma(\phi \to 3\pi)$ = 0.65 MeV Zweig rule violated



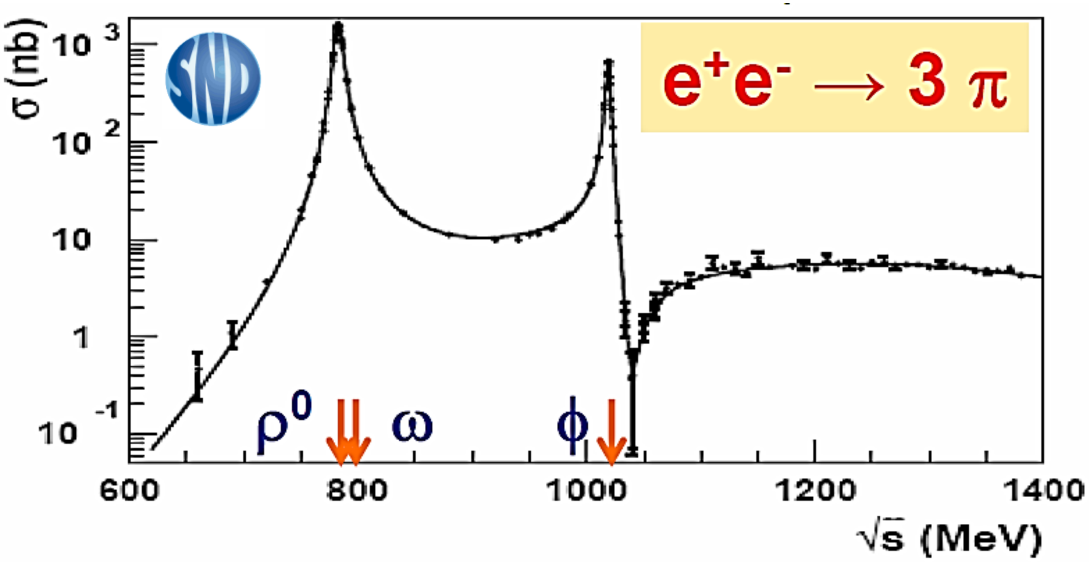

- Bkg near $\phi$ changes slowly

  ⇓

  nearly standard interference curve,
  instead of $\phi$–peak:
  both bump & dip,
  each has form different from BW;
  max/min different from $\phi$-*mass* $\rho$.

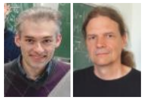
- $\rho$-contribution here deforms $\omega$-*tails*.

- Curve is fit with $\omega$, $\phi$, $\rho$, $\omega'$, & $\omega''$.



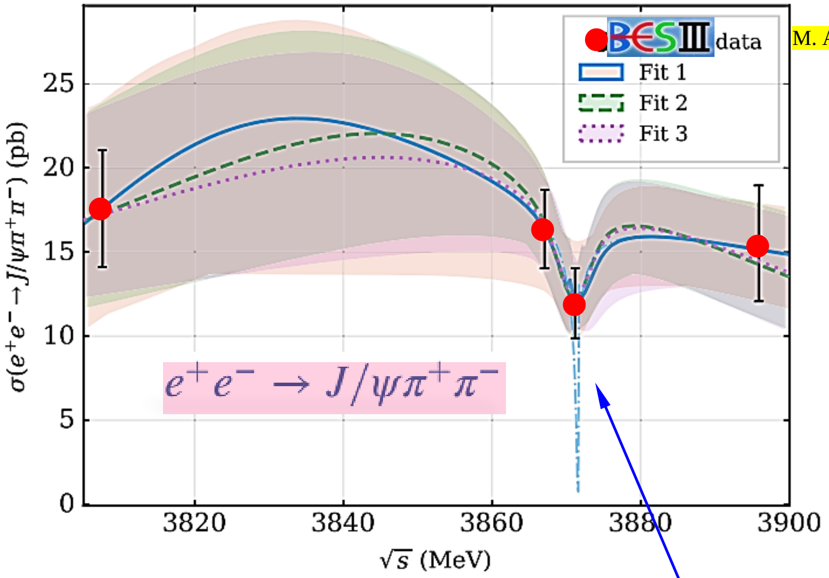

M. Achasov, Nucl Phys B Proc Suppl **162**, 114 (**2006**)

V. Baru, F.-K. Guo, C. Hanhart, & A. Nefediev, Phys Rev D **109**, L111501 (**2024**)

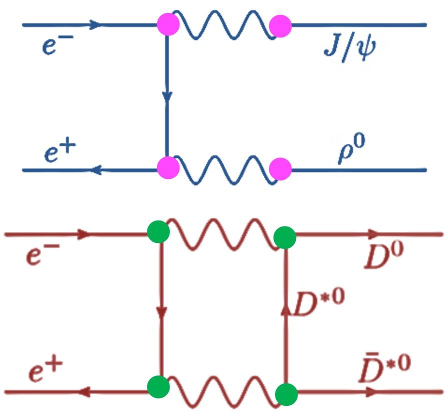


## • How does X(3872) show up in $e^+e^-$ collisions.

- We demonstrate that the dip observed near the total energy of 3872 MeV in the recent cross section data from the BESIII Collaboration for $e^+e^- \to J/\psi\pi^+\pi^-$ admits a natural explanation as a coupled-channel effect: it is a consequence of unitarity and a strong $S$-wave $D\bar{D}^*$ attraction that generates the state $X(3872)$. We anticipate the appearance of a similar dip in the $e^+e^- \to J/\psi\pi^+\pi^-\pi^0$ final state near the $D^*\bar{D}^*$ threshold driven by the same general mechanism, then to be interpreted as a signature of the predicted spin-2 partner of the $X(3872)$.

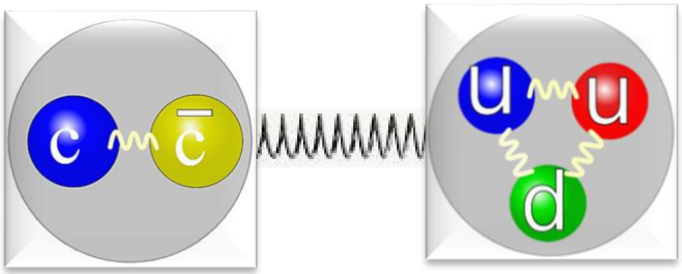


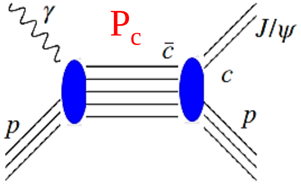

M. Ablikim *et al*, Phys Rev D **107**, 032007 (**2023**)




• Effect is small, but visible & more *statistics* is in order.

# Alternative Solution for GlueX $J/\psi$ Data & Cusp Effect






# *Recipe for Possible Interpretation of* GlueX *Dip*

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

- Experimental total Xsec of inelastic binary reaction: $\sigma_t = \int_0^{2\pi}\int_0^{\pi}\frac{d\sigma}{d\Omega}\sin\theta\, d\theta\, d\phi$

*J/ψ polar* production *angle*

*J/ψ azimuthal* production *angle*

Photon CM *momentum*

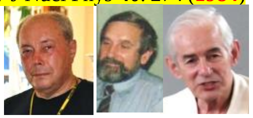
- Phenomenological total Xsec: $\sigma_t = \frac{\pi}{4k^2}\sum_{J=0}^{\infty}(2J+1)\,|f|^2$

Using *Landau-Livshitz* normalization

*Total angular momentum*
*(2J+1)* = 1 for ***S***-wave
= 3 for ***P***-wave

- Partial Amplitude: $f = b + R\cdot\exp(2i\alpha)$

IIS, A.V. Kravtsov, & M.G. Ryskin, Sov J Nucl Phys **40**. 274 (1984)



There is 1 free parameter for *interference* ***α***

Relative *phase shift*

It comes from **fit** of total Xsec

- Non-Res: $b = \sqrt{A\,q\;+\;B\,q^3}$

*V* CM *momentum*

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

There are 2 free parameters for *background* ***A*** & ***B***

*Energy* ***independent width*** (***P$_c$*** is too *narrow*)

***Mass***

- Relativistic **BW**: $R = \frac{2\Gamma M}{[(M)^2 - s] - i\Gamma M}X$

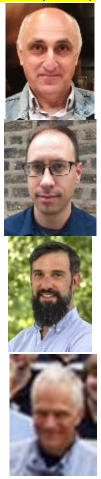
*Partial decay widths* of
**P$_c$→γp** & **P$_c$→J/ψp**.

- Partial Width: $X = \frac{\sqrt{\Gamma(\gamma+p)\,\Gamma(J/\psi+p)}}{\Gamma} = \sqrt{X(\gamma+p)\,X(J/\psi+p)}$

There are 3 free parameters for *resonance* ***M***, ***Γ***, & ***X***

# Alternative Solution for GlueX Data

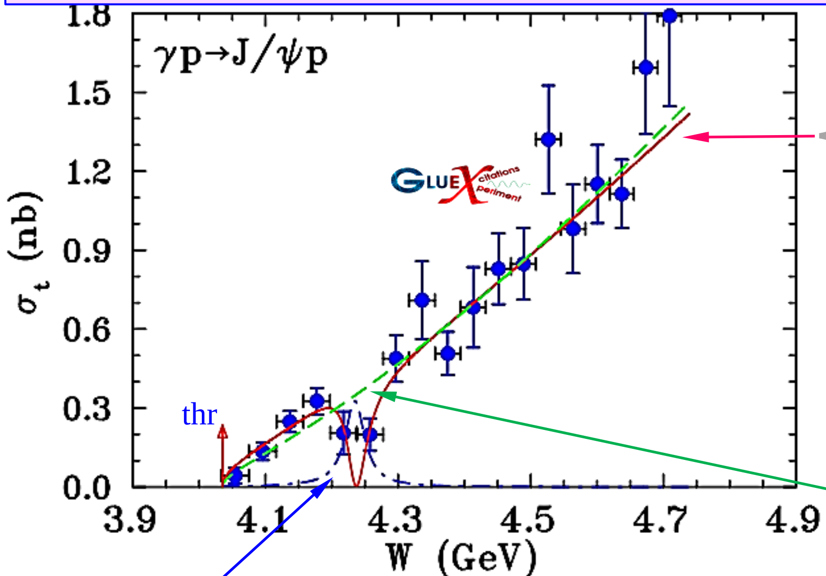
IIS, W.J. Briscoe, E. Chudakov, I. Larin, L. Pentchev, A. Schmidt, & R.L. Workman, Phys Rev C **108**, 015202 (2023)
S. Adhikari *et al*, Phys Rev C **108**, 025201 (2023)



- 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: $\chi^2$/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

Background:
**A**= 0.00251±0.00046 nb GeV/c
**B**= 0.00688±0.00083 nb/GeV/c

No Resonance: $\chi^2$/ndf=19.74/16=**1.23**
**A**= 0.00183±0.00040 nb GeV/c
**B**= 0.00766±0.00077 nb/GeV/c

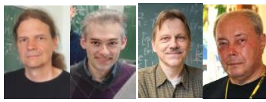
- *Dip position* does not correspond to *real mass* of **P$_c$(4312)$^+$**.
- It may depend on reaction *mechanism* [including *cusps* (***open charm***)] & background choices.

- If "*bump*" is imposed on GlueX data "*by hand*" (consider 7th - 9th energy values up from threshold), qualitative description of data up to **W** = **4.35** GeV is possible, but with higher $\chi^2$, if our fit form is used.

- Obtained mass in our analysis is almost **77** MeV below LHCb determination, but it cannot exclude that this is P$_c$(4312)$^+$.

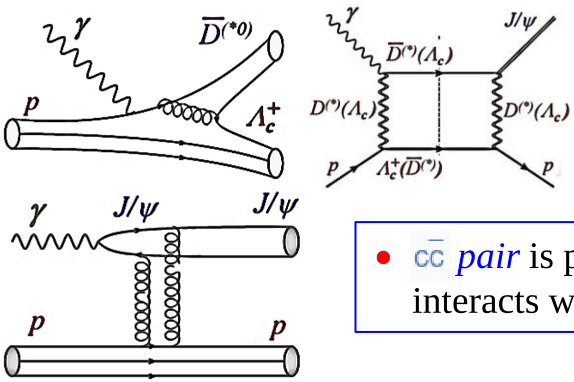
# *Deciphering Mechanism of Near-Threshold J/ψ Photoproduction*

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* $\gamma p \rightarrow \Lambda_c \bar{D}$ .
  is preferable than into *Charmonium J/ψ*.

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



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

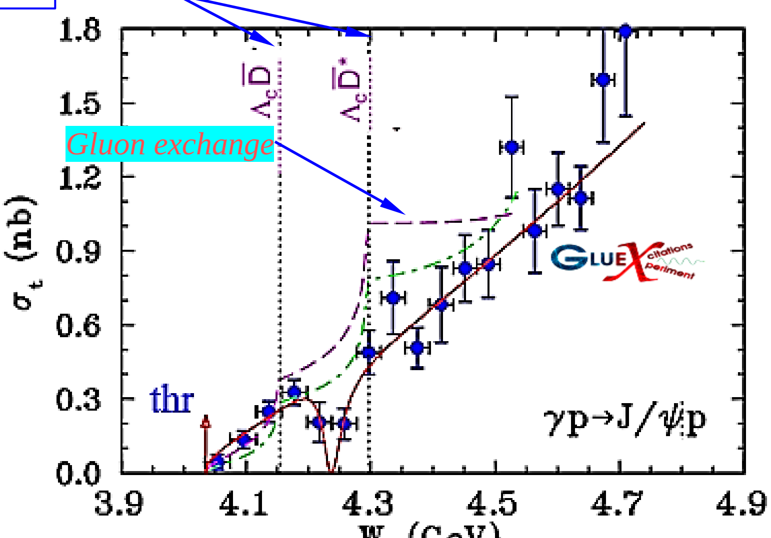
- $c\bar{c}$ *pair* is produced by *photon* via *VMD* & interacts with *proton* through *2g* exchange.

- 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

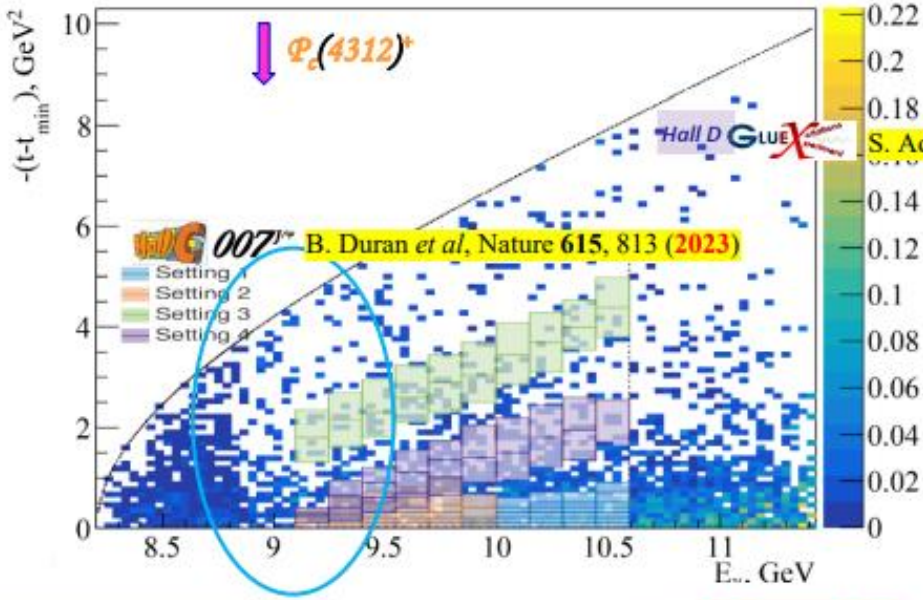
- ***Cusp*** effect is visible & in agreement with GlueX.




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

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

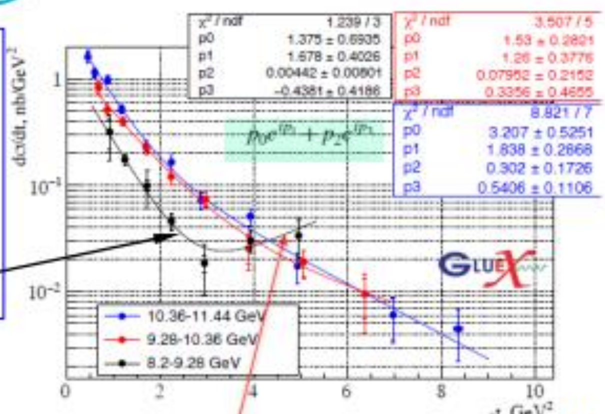
# $J/\psi$ Threshold Region Coverage




PDG BR($J/\psi \to e^+e^-$) = (5.971±0.032)%

BR($J/\psi \to \mu^+\mu^-$) = (5.961±0.033)% In progress

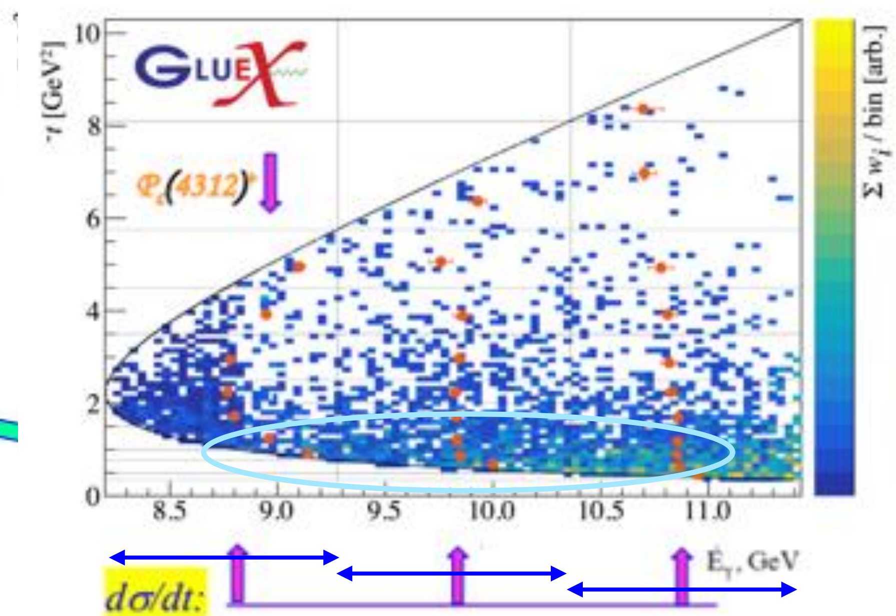
- Data is fitted with sum of two exponential functions.
- Second exponential contribution is most significant in lowest energy bin, where slope changes sign.

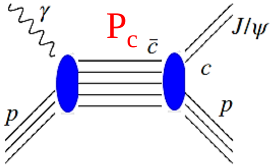



- Exponentially falling $t$-dependence

however:

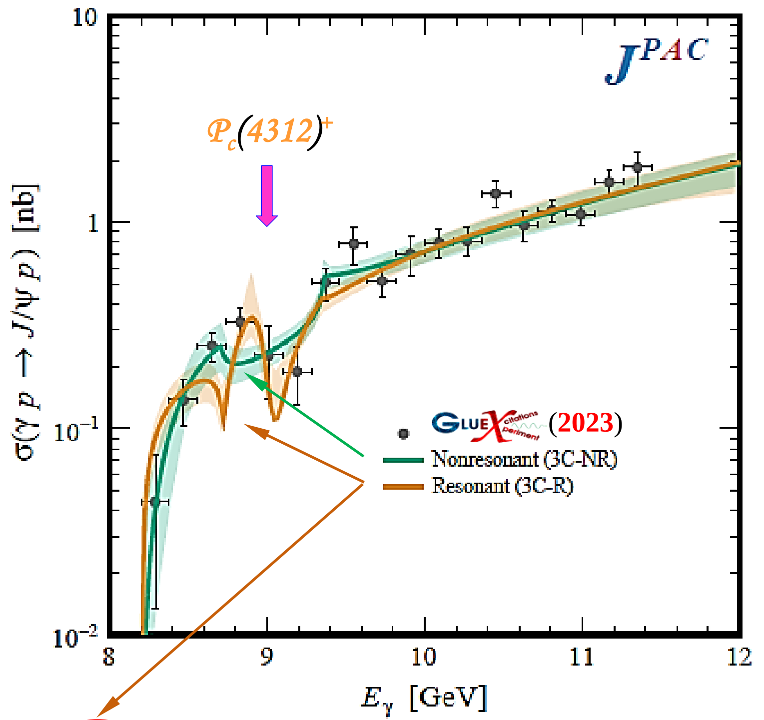
- Enhancement of $d\sigma/dt$ at high t (for the lowest energy slice), indicates contribution beyond gluon exchange






# $J^{PAC}$ for $J/\psi$ Photoproduction

D. Winney *et al*, Phys Rev C **108**, 054018 (2023)




***Phenomenological*** model based on **s**-channel PW expansion ($l < 3$):

- *Global fit of both GlueX & Hall **D** dσ/dt(t) & Hall **D** $\sigma_{tot}(E_\gamma)$*
  - (1C) $J/\psi p$ interaction
  - (2C) $J/\psi p$ interaction & $\bar{D}^*\Lambda_c$
  - (3C–NR) $J/\psi p$, $\bar{D}\Lambda_c$, $\bar{D}^*\Lambda_c$ (non-res soln)
  - **(3C–NR) $J/\psi p$, $\bar{D}\Lambda_c$, $\bar{D}^*\Lambda_c$ (res soln)**

- No stat significant preference:
  - $E_\gamma$ = **9** GeV structure requires sizable contribution from *open charm*.
  - Severe violation of **VMD** & factorization *not excluded*.
  - s-channel resonance *not excluded*.
  - t-enhancement maybe due to *proximity* to threshold (**s**-wave only).

$|a_{\psi p}| \lesssim 0.2$ fm at a 90% CL → Much-much larger than we found.

*Pole position*
(no uncertainties)
$M_R$ = **4211** MeV
$\Gamma_R$ = **48** MeV

→ **101** MeV below LHCb
**24** MeV below us

- Precise measurements critically important to disentangle *reaction mechanism* @ *threshold*.

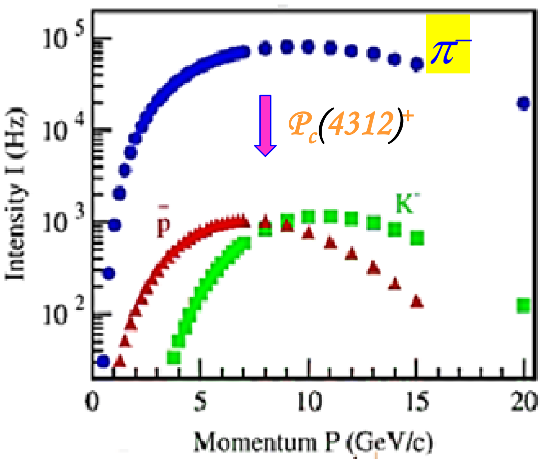
# J-PARC Pion Induced Measurements

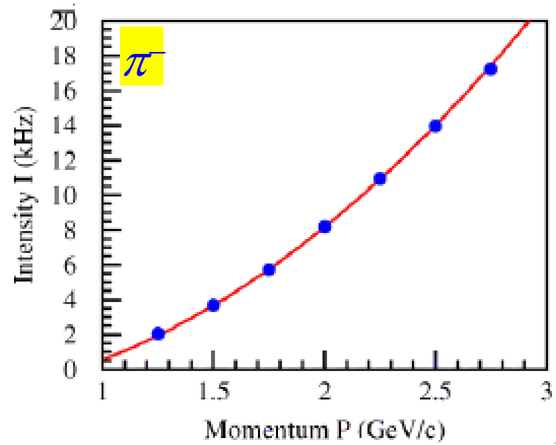
# J-PARC for $\pi^- p \to J/\psi\, p$

*High-p*, 2024

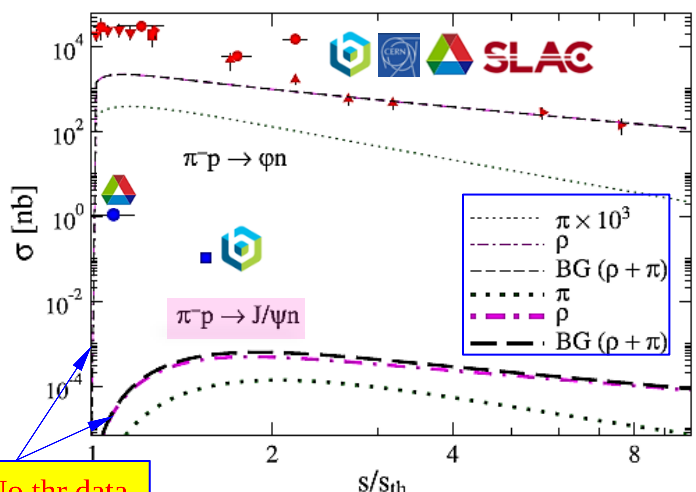
Bump Hunting

- Hidden Charm Production



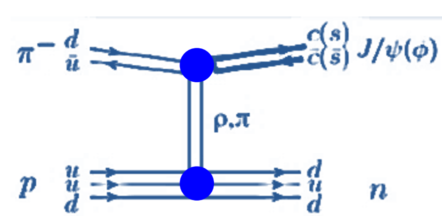




- *High-p* can detect $J/\psi$ to $e^+e^-$ & $\mu^+\mu^-$ pairs.
- *High-p* can use incident beam
  **P** = **2** – **20** GeV/c from **π20** beamline.
- One can measure $J/\psi$ production @
  **P** = **8** – **10** GeV/c.
- $\mathbf{W_{thr}}$ = **4** GeV ($\mathbf{P_{thr}}$ = **8.06** GeV/c).
- Momentum bite is expected to be ±3%.




$10^6$

$g_{\phi\rho\pi} > g_{J/\psi\rho\pi}$

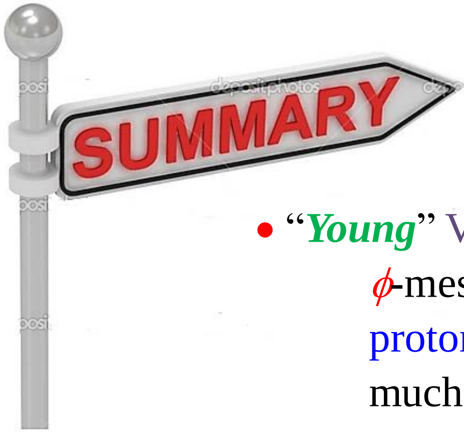



No thr data

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

- New *High-p* measurement allows to understand dynamics of $c\bar{c}$ production @ threshold.
- It is free from **VMD** & allows to determine $J/\psi$ p **SL** independently on GlueX
- It allows to look for effect of LHCb $P_c$

# Summary




- "***Young***" V hypothesis may explain fact that obtained **SL** value for $\phi$-meson nucleon compared to typical hadron size of 1 fm indicates that proton is more transparent for $\phi$-meson compared to $\omega$-meson & is much less transparent that $J/\psi$-meson. $|\alpha_{\Upsilon p}| << |\alpha_{J/\psi p}| << |\alpha_{\phi p}| << |\alpha_{\omega p}|$

- & ability allows us to understand dynamics of $s\bar{s}$ & $c\bar{c}$ & $b\bar{b}$ production @ threshold & to look for effect of LHCb $P_c(4312)$.

- Further studies on both nucleons & nuclei in *heavy* V photo- & electro-production will significantly extend our knowledge of gluonic structure of nuclear matter.

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

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

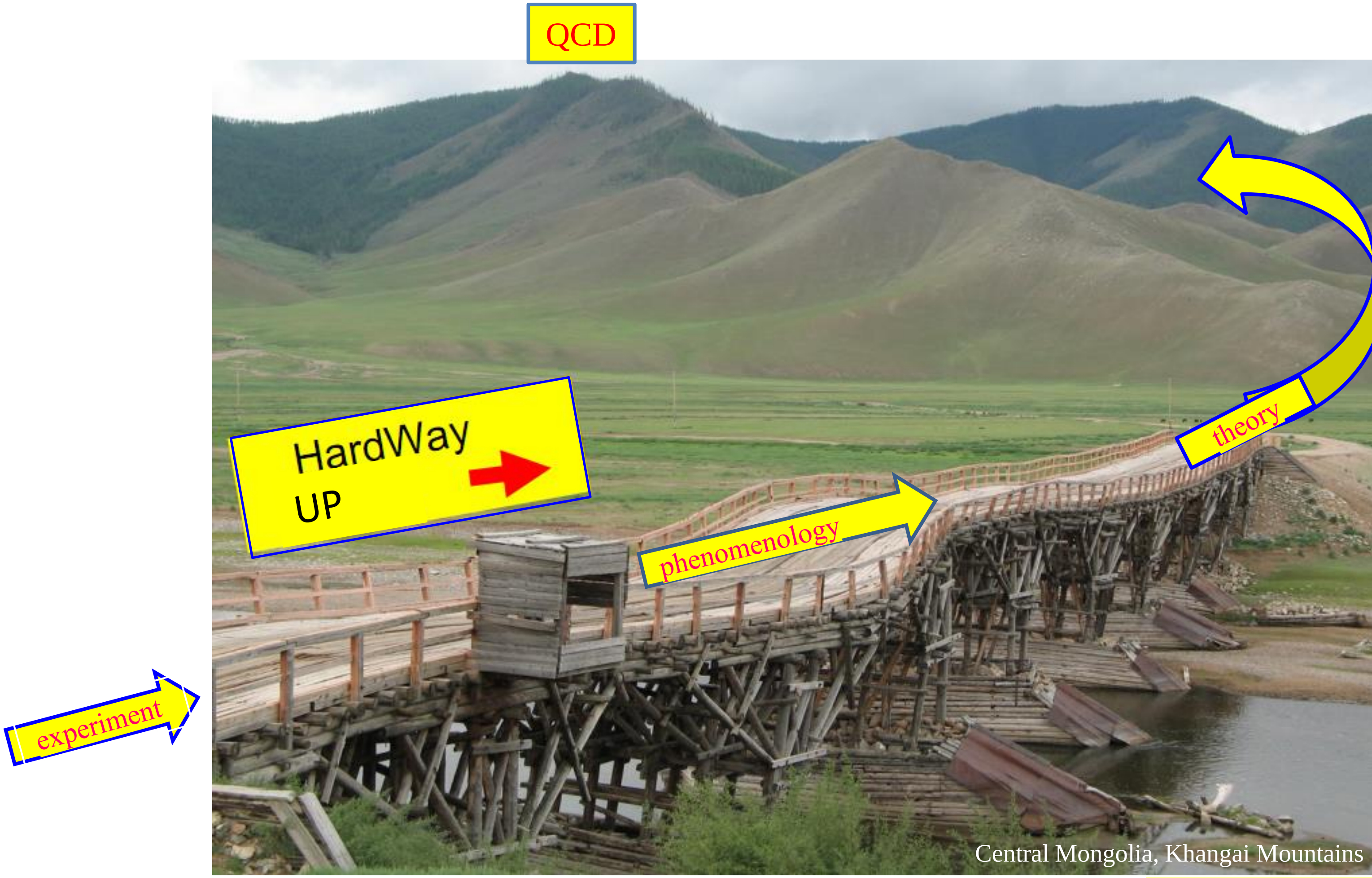
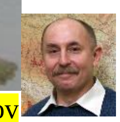



Photo of Pavel Azimov



非常感謝

Do you have any questions to speaker?

歡迎提問

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