Is the LHCb $P_c(4312)^+$ Plausible in the GlueX $\gamma p \to J/\psi p$ Total Cross Sections?

Igor Strakovsky

The George Washington University

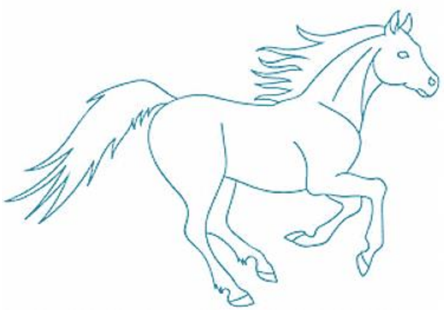
Joint work with *Bill Briscoe*
Eugene Chudakov
Ilya larin
Lubomir Pentchev
Axel Schmidt
Ron Workman

- ***J/ψ*** photoproduction is sample of hard process corresponding to relatively large scale.
- Quality of novel GlueX ***J/ψ*** photoproduction data & proximity of data to energy threshold, gives access to variety of interesting physics aspects.
- Examples are ***trace*** *anomaly*, estimation of ***J/ψ-N*** *scattering length*, ***5q*** *exotics*, & so on.

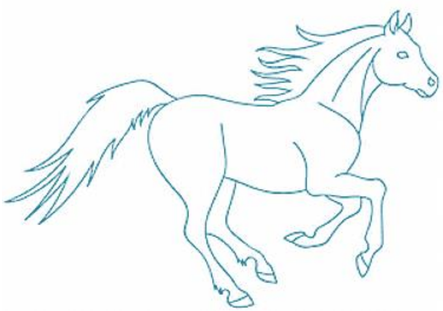
IIS, W.J. Briscoe, E. Chudakov, I. Larin, L. Pentchev, A. Schmidt, R.L. Workman, Phys Rev C **108**, 015202 (2023)

Supported by DE-SC0016583

Outline

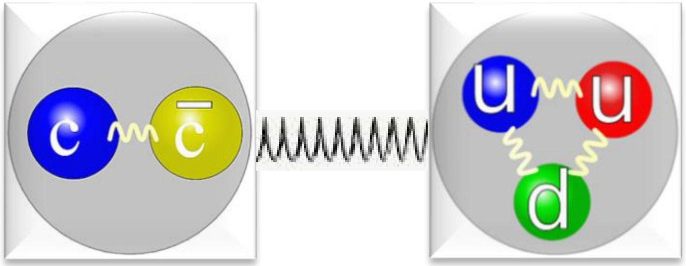


- *Narrow pentaquarks from LHCb - Big question.*
- *GlueX J/ψ photoproduction in 2019 & 2023.*
- *Intermission: Quantum interference of particles & resonances.*
- *Alternative solution for GlueX J/ψ data.*
- *Cusp effect.*
- *Vector meson – nucleon scattering length.*
- *JPAC for J/ψ photoproduction.*
- *SOLID for more J/ψ photoproduction.*
- *JLab at High Energies.*
- *J-PARC for J/ψ.*
- *Summary.*



Narrow Pentaquarks from LHCb

- Big Question



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

- 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

CI=4032

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 (q q q), (q q q q q̄), etc., while mesons are made out of (q q̄), (q q q̄ q̄), etc.

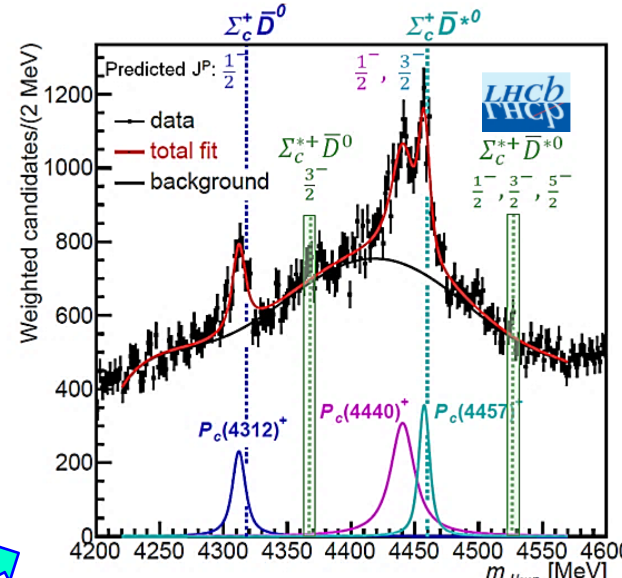
- Many $\bar{q}q$ & qqq states have been *observed*.

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 $\Lambda_b \to J/\psi\, p\, K^-$ decays.

State	M	$\Gamma[Pc \to J/\psi + p]$	Significance
	(MeV)	(MeV)	
$P_c(4312)^+$	$4311.9 \pm 0.7^{+6.8}_{-0.6}$	$9.8 \pm 2.7^{+3.7}_{-4.5}$	7.3 σ
$P_c(4337)^+$	$4337^{+7}_{-4}{}^{+2}_{-2}$	$29^{+26}_{-12}{}^{+13}_{-14}$	3.1 – 3.7 σ
$P_c(4440)^+$	$4440.3 \pm 1.3^{+4.1}_{-4.7}$	$20.6 \pm 4.9^{+8.7}_{-10.1}$	5.4 σ
$P_c(4457)^+$	$4457.3 \pm 0.6^{+4.1}_{-1.7}$	$6.4 \pm 2.0^{+5.7}_{-1.9}$	5.4 σ



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

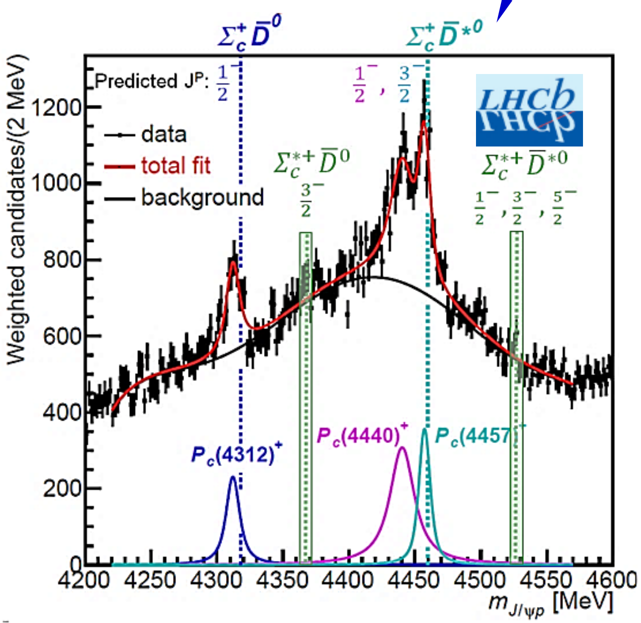
CI=631

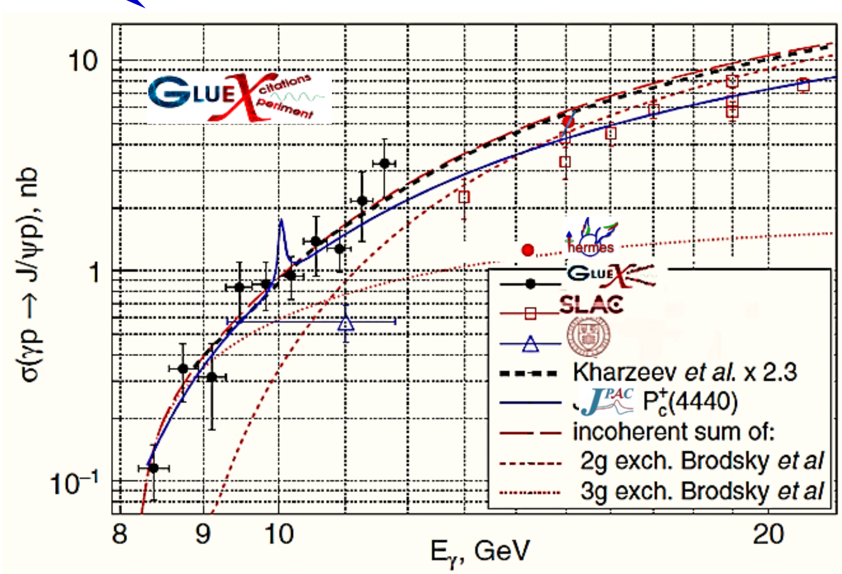
- Bump *hunting*:
  - no *quantum numbers*
  - no *pole positions*

Big Question

Bump Hunting

- Why LHCb has chance *to see hidden-charm pentaquark states* while it *is elusive* in GlueX ?
- There is no confirmation of this LHCb observation PDG.

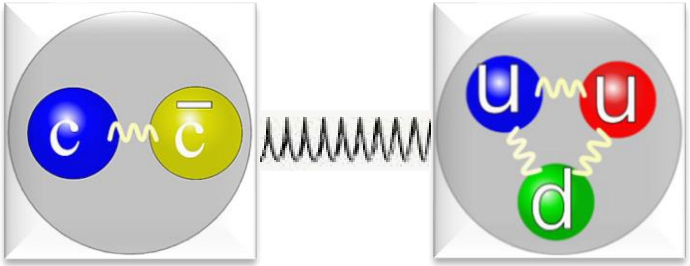




"Not every bump is a resonance, not every resonance is a bump"
R. Gordon Moorhouse (**1960s**)

GlueX J/ψ Photoproduction

in 2019 & 2023



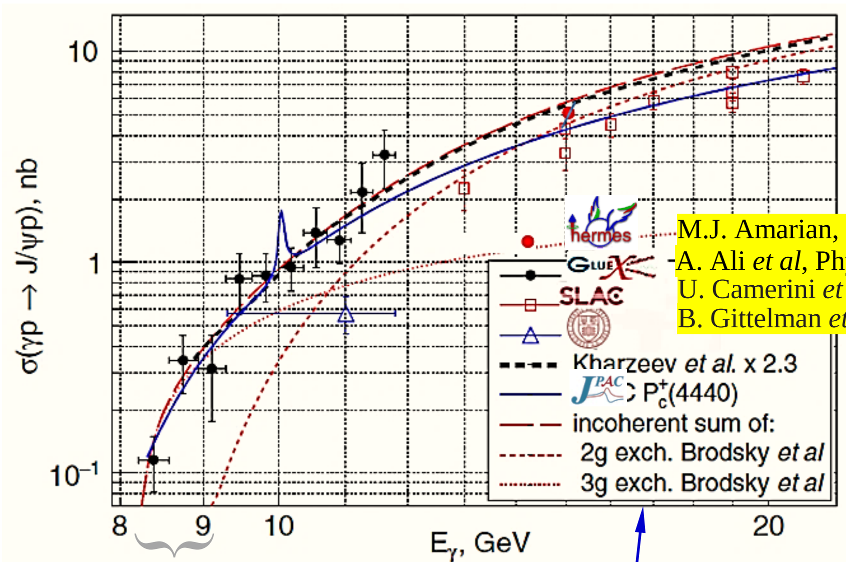
How Bump Hunting works in 2019 GlueX data ?

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

CI=170

Editors' Suggestion

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



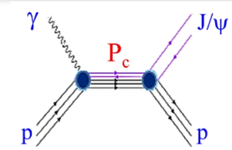
M.J. Amarian, Few-Body Syst Suppl. **11**, 359 (**1999**)
A. Ali *et al*, Phys Rev Lett **123**, 072001 (**2019**)
U. Camerini *et al*, Phys Rev Lett **35**, 483 (**1975**)
B. Gittelman *et al*, Phys Rev Lett **35**, 1616 (**1975**)

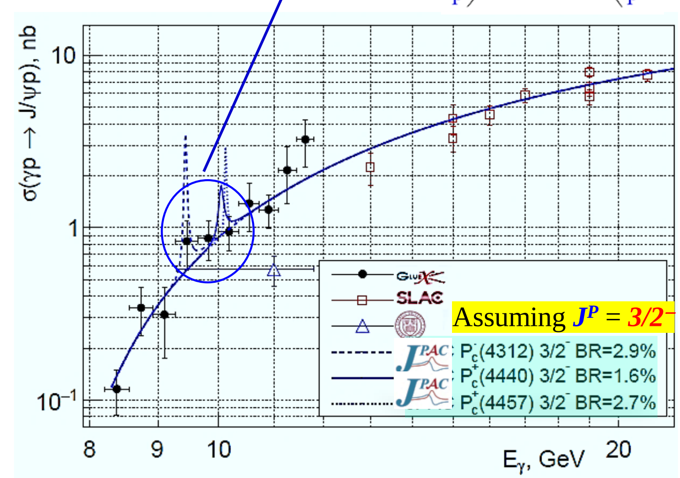
D. Kharzeev, H. Satz, A. Syamtomov, & G. Zinovjev, Nucl Phys A **661**, 568 (**1999**)
JPAC A.N. Hiller Blin *et al*, Phys Rev D **94**, 034002 (**2016**)
S. Brodsky, E. Chudakov, P. Hoyer, & J.M. Laget, Phys Lett B **498**, 23 (**2001**)

- ***3g*** works better than ***2g*** *@ threshold*

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

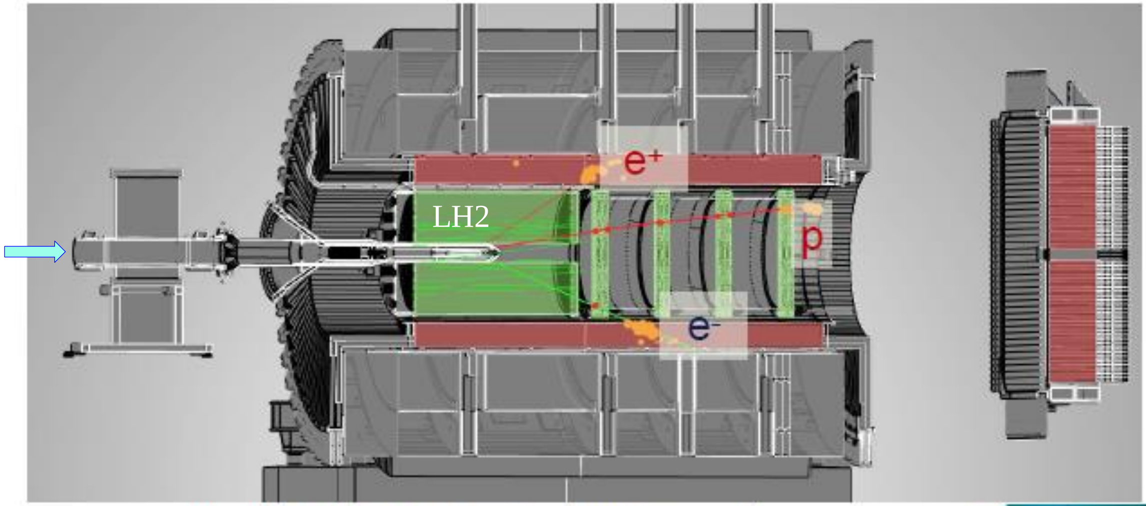
State	Upper Limit
$P_c(4312)$	**4.6** %
$P_c(4440)$	**2.3** %
$P_c(4457)$	**3.8** %





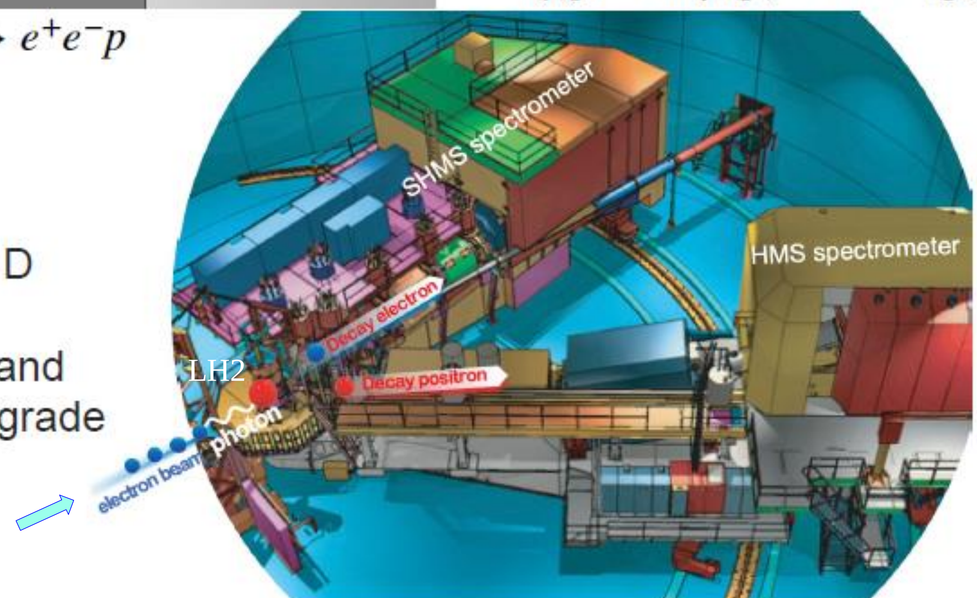
Recent (and future) Jefferson Lab results on threshold charmonium photoproduction

Lubomir Pentchev
(GlueX Collaboration)



Hall D GlueX $\gamma p \to J/\psi p \to e^+e^-p$

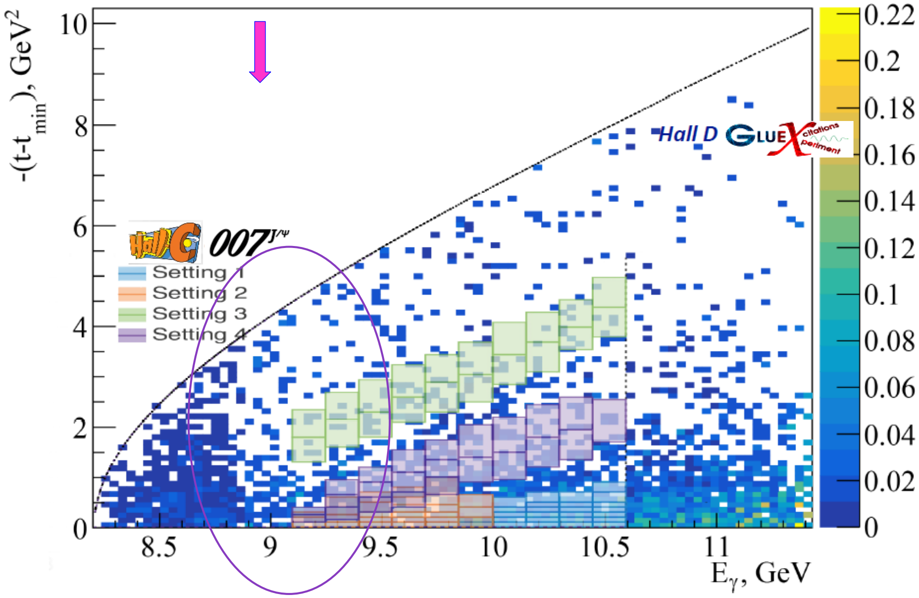
Hall C 007$^{J/\psi}$
$(\gamma)p \to J/\psi(p) \to e^+e^-(p)$



- Recent J/ψ results from Hall C & D
- … and their interpretation
- Higher-mass charmonium states and prospects with CEBAF energy upgrade using GlueX detector

Courtesy of Lubomir Pentchev, 2023

J/ψ Threshold Region Coverage

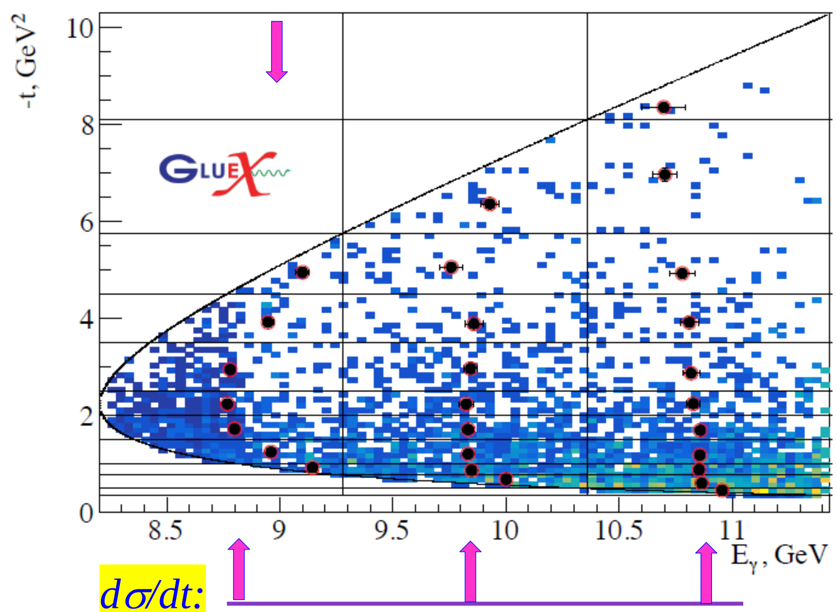


Courtesy of Lubomir Pentchev, 2023

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

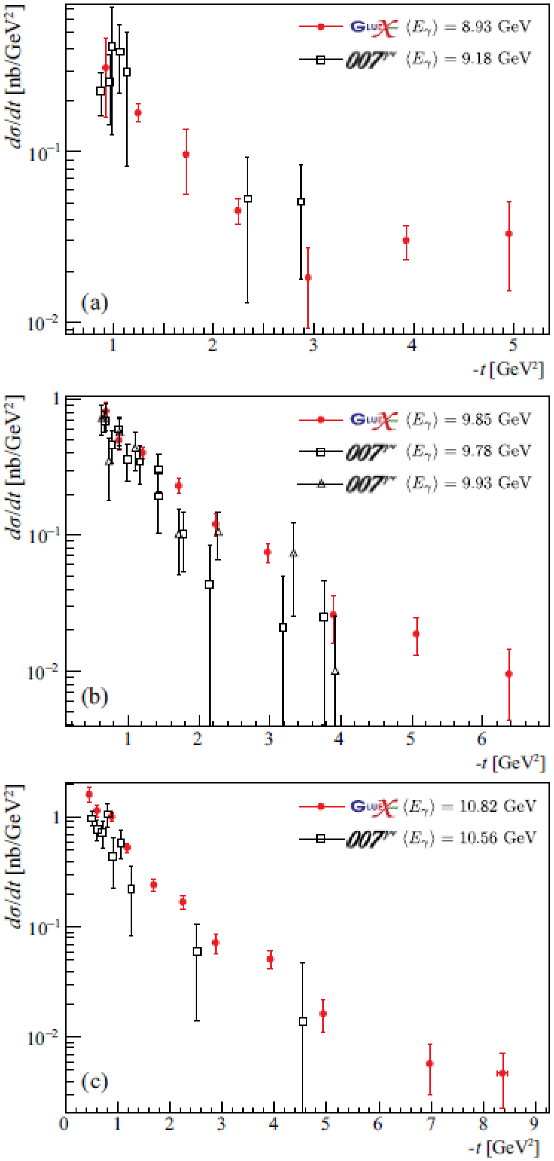
BR($J/\psi \to \mu^+\mu^-$) = (5.961±0.033)%

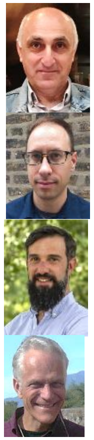
In progress

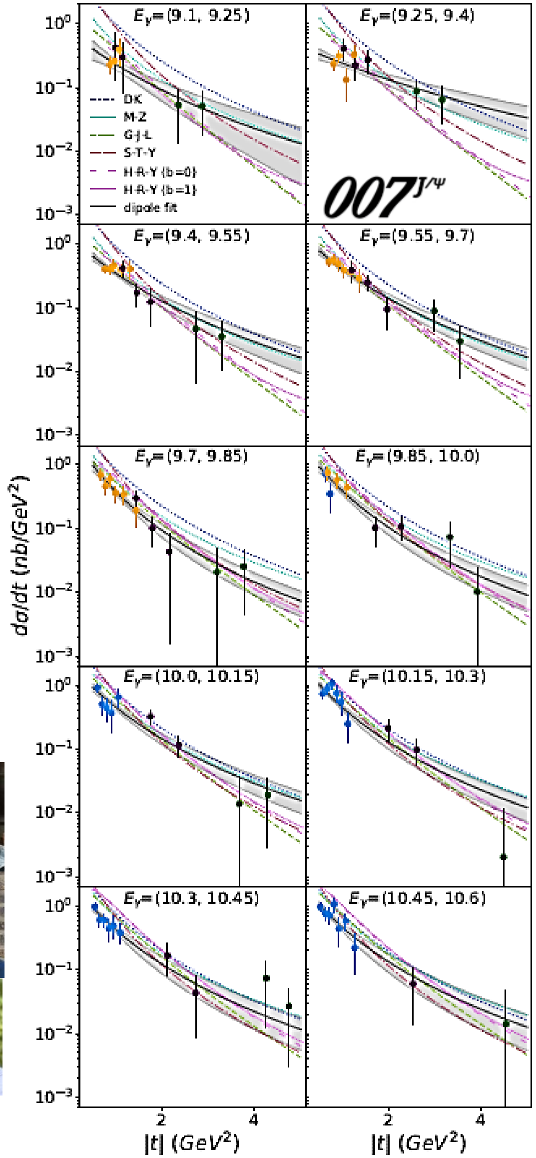


$d\sigma/dt$:

Differential Cross Sections from J/ψ by 007$^{J/\psi}$ & GlueX







- **10** energy bins in 007$^{J/\psi}$.
- Results for **3** GlueX **energy bins** compared to closes 007$^{J/\psi}$ energies.
- Scale/Norm uncertainties: **20**% in GlueX & **4**% in 007$^{J/\psi}$ results.
- Good agreement within s.

S. Adhikari *et al*, Phys Rev C **108**, 025201 (**2023**) **CI=8**

B. Duran *et al*, Nature **615**, 813 (**2023**) **CI=26**

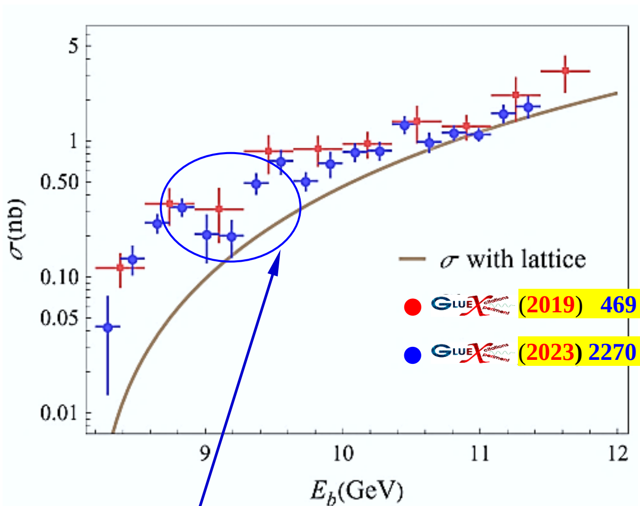
Editors' Suggestion

How Bump Hunting works in 2023 GlueX data ?

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

CI=10

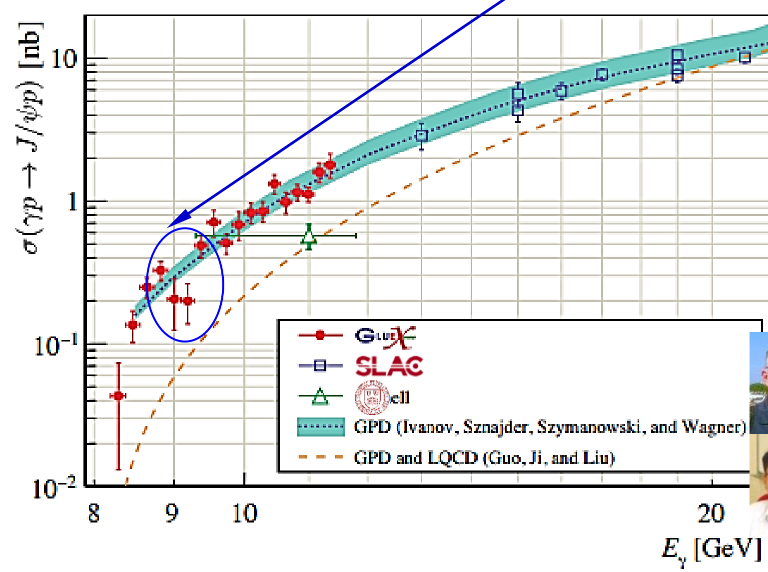
2016–2018 data: **2270**±58 $\gamma p \to J/\psi p \to e^+e^- p$ & **320** pb^{-1}



Y. Guo *et al*, Phys Rev D **108**, 034003 (**2023**)

- ***Dip***, close to $\mathbf{E}_\gamma$ = **9.2-9.3** GeV, deepened with growing GlueX statistics (by factor of **5**).
- Data taken in **2020** will additionally *increase statistics* by factor of **2**.

- If GlueX treats two total Xsec points in vicinity of **W** = 4.2-4.3 GeV as potential ***dip*** (considering *stat* & *point-to-point syst* uncertainties), probability that they are not *stat fluctuation* from underlying smooth fit to observed Xsec corresponds to significance of **2.6 σ**.



Intermission

Quantum Interference of Particles & Resonances

IOP Publishing — Journal of Physics G: Nuclear and Particle Physics

J. Phys. G: Nucl. Part. Phys. 37 (2010) 023001 (22pp) doi:10.1088/0954-3899/37/2/023001

TOPICAL REVIEW

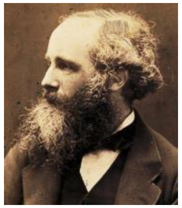
Quantum interference of particles and resonances

Ya Azimov

Petersburg Nuclear Physics Institute, Gatchina 188300, Russia

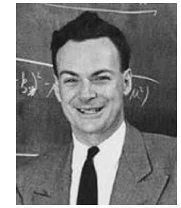
CI=18

Interference - *I*



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

- *Quantum physics* is probabilistic.
- *Classical physics* can be probabilistic as well (Statistical physics).

- Essential difference:
  Classical Physics adds *probabilities*.
  Quantum Physics adds *amplitudes*.

- Important consequence:
  possibility of interference effects;
  various *wave functions* may mix.

- Impressive result:
  particles may oscillate in *time*,
  transforming to *each other*.

Most Famous Examples:

- Beauty *oscillations* –
  in decays of neutral *B*-mesons (@ *some* μm)
  (coherent *oscillations* of several flavors are also possible)

Ya. Azimov, Phys Rev D **42**, 3705 (**1990**); Eur Phys J A **4**, 21 (**1999**)

- Strangeness *oscillations* –
  in decays of neutral *K*-mesons (@ *~10 cm*)

- Neutrino *oscillations* –
  (up to *hundreds km*,
  or even *astronomical* distances **!** Solar ν)
  Wide variety of *macroscopic* distances!

- Quite *macroscopic* manifestations of *quantum microscopic* effects **!**

- Same phenomenon may be *seen* in complementary variable – energy (mass in rest frame):
- It is seen here as *deformation* of **BW** peaks.

- Pure BW term: $|a\,(E - E_0 + i\,\Gamma/2)^{-1}|^2 = |a|^2\,[(E - E_0)^2 + \Gamma^2/4]^{-1}$

- BW with background: $|B + a\,(E - E_0 + i\,\Gamma/2)^{-1}|^2$

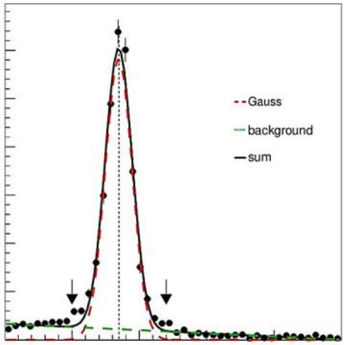
$$= |B|^2$$

may depend on ***E***

$$+\, |a|^2\,[(E - E_0)^2 + \Gamma^2/4]^{-1}$$

$$+\, [2\,|B\,a|\cos\phi\,(E - E_0) + |B\,a|\sin\phi\,\Gamma] \times [(E - E_0)^2 + \Gamma^2/4]^{-1}$$

interference term



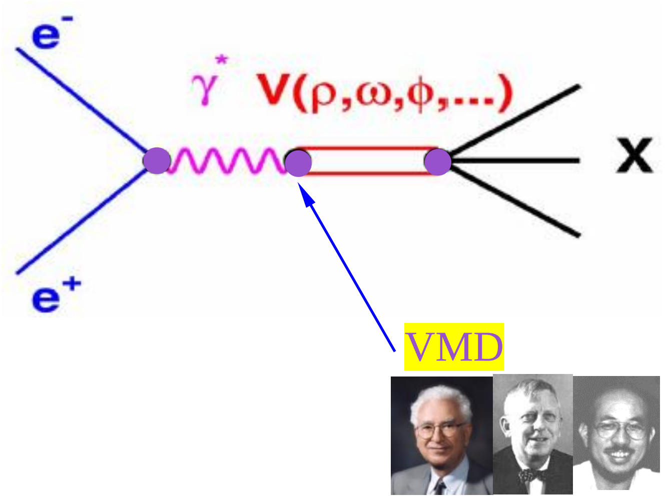
role of interference depends on relative value & on relative phase ϕ of ***B*** & ***a***;
it is *linear* in ***a***, may change sign & be either positive or negative.

- @ small value of |***a***/***B***| interference term may be more essential than proper **BW** contribution.
- Due to additional ***E***-dependence, interference *may change **sign***, provide either bump, or dip, or both.
- Bump &/or dip positions are, in general, shifted from *true position* of resonance.
- Same resonance may interfere differently in different decay modes.

- Rich source of examples, how interference works, is provided by reaction $e^+e^- \rightarrow hadrons$.

- Contributions with *same* final state are coherent;
  they all are produced through γ/Z & may directly interfere,
  if have *same* decay mode.

- Independent contribution of resonance is BW-peak,
  proportional to $\Gamma_{ee}\,\Gamma_X / \Gamma_{tot}$.
  Interference may change its form & intensity.



Interference - VI

PDG $\Gamma(\rho)$ = 149.4 MeV; $\Gamma(\omega)$ = 8.5 MeV; $\Gamma(\varphi)$ = 4.3 MeV

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

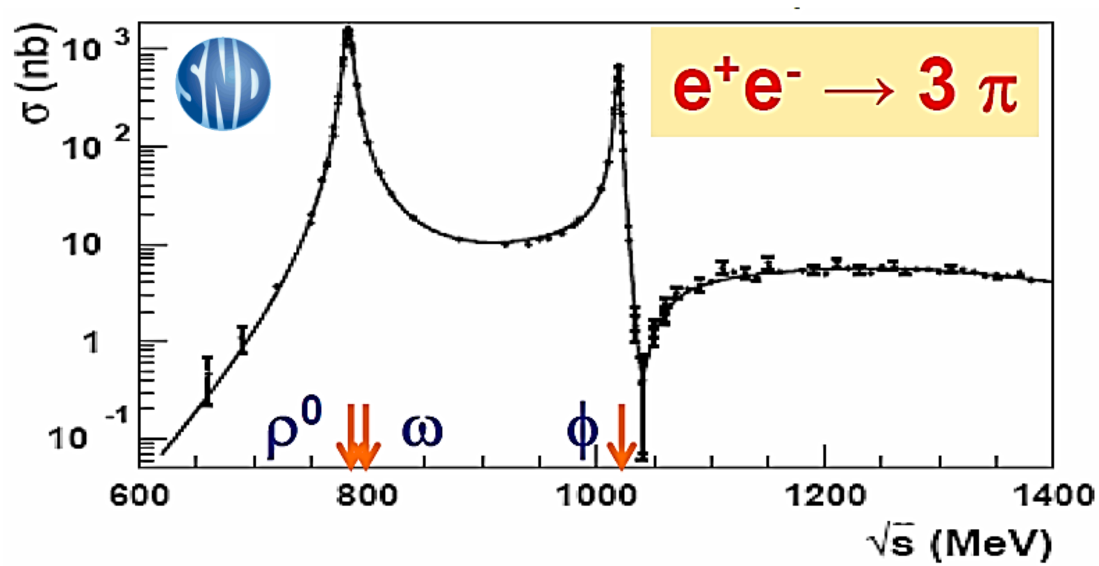
- Bkg near φ changes slowly

  ⇓

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

- ρ-contribution here deforms ω-*tails*.

- Curve is fit with ω, ϕ, ρ, ω', & ω''.



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

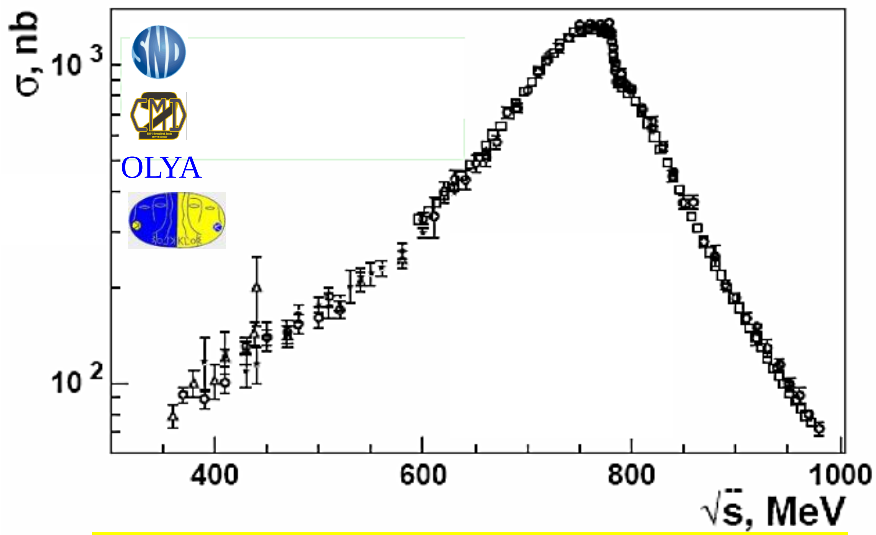
$e^+e^- \to \pi^+\pi^-$ *for Interference - VII*

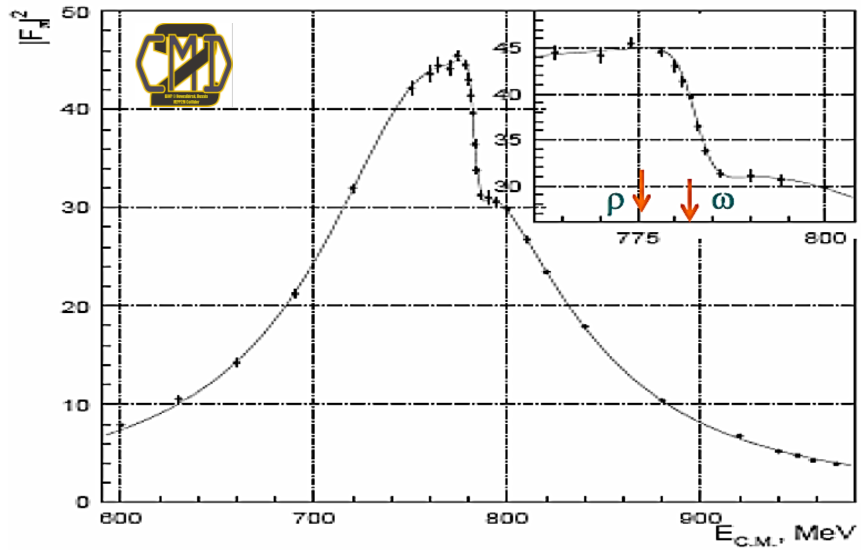
R.R. Akhmetshin *et al*, Phys Lett B **648**, 28 (2007)

isospin violated

$\Gamma(\rho^0 \to 2\pi) = 148$ MeV

$\Gamma(\omega \to 2\pi) = 0.13$ MeV





- **Most famous example of resonance interference.**

- All above examples demonstrate
  direct interference of 2 resonances:
  all final particles can be decay products
  of any of the interfering resonances.
- Such kind of interference appears very efficient
  to search for rare decays of known resonances.
  may strongly deflect resonance manifestation
  from familiar BW peak.
- There can be other kinds of interference,
  where only some of final particles may come
  from any of 2 interfering resonances.

- Specifics of this case:
  rapidly decreasing bkg (ρ–peak);
  ρ–ω mixing may (& does) have complexity

Y.I. Azimov, Eur Phys J A **16**, 209 (2003)

$\Rightarrow$ interference curve is strongly asymmetric:
decrease, no increase.

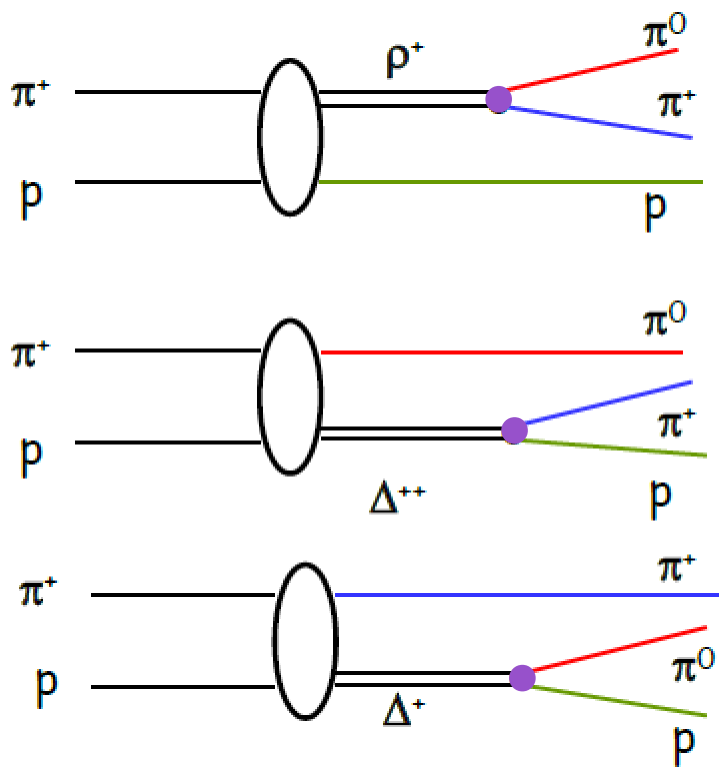
- Opposite relative sign would reveal additional peak (case of $\eta\gamma$).

- **Interference is only source of information on decay $\omega \to 2\pi$.**

Rescattering Interference - I

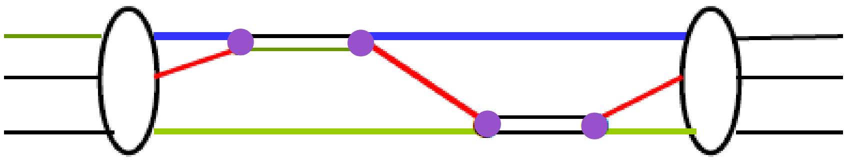
- Different resonance configurations may produce same state of 3 or more particles.
- Such contributions are coherent & may interfere.

- Contributions depend on energies & momentum transfers; may shift & move positions of bumps/dips.



- Phenomenon is known since **60**s.
- It was considered as *hindrance* to resonance studies.

- This interference was usually (& is still now) cut away.



- Name rescattering reflects similarity with rescattering in 3-particle interactions: one particle changes its interaction partner.

- On other side, this kind of interference is like the famous case of 2 *quantum slits*, since one particle refers simultaneously to 2 resonances.

- Resonances are in <u>different</u> systems & may have <u>different</u> quantum numbers but final states, after resonance decays, should contain same particles.

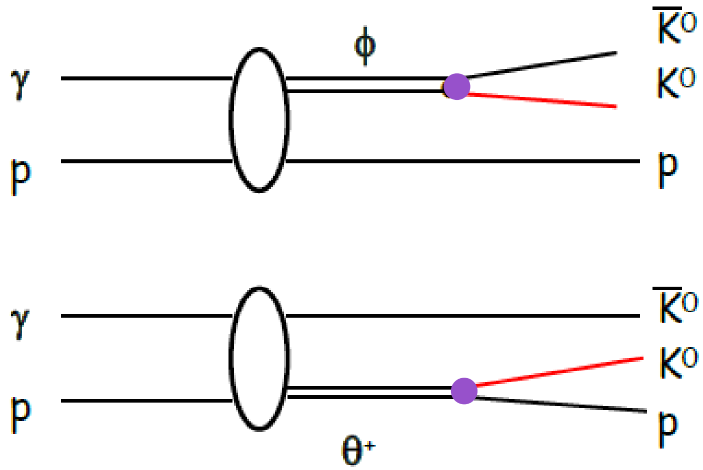
- **2** resonances can interfere, only if final configurations are kinematically consistent.

⇒

- This requires limited intervals of total energy & momentum transfers.

- Positions of interference bumps/dips, generally, depend on kinematic parameters & *move* with their changes (in difference with *true* resonance positions).

- Direct interference of resonances has become efficient instrument actively used to study *rare decays* of known resonances.



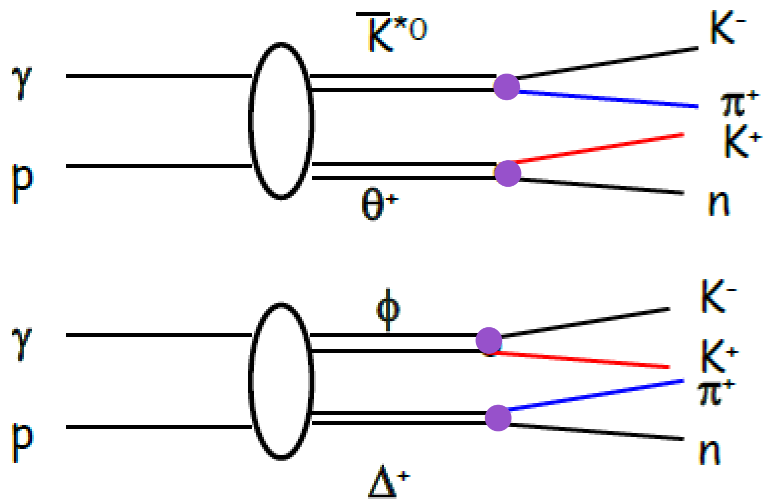
- Amaryan, Diakonov, Polyakov have suggested to apply rescattering interference for revealing small new resonance signals (amplification by *interference* with strong signal).

M. Amarian, D. Diakonov, & M.V. Polyakov, Phys Rev D **78**, 074003 (**2008**)
CI=**22**

- *Θ*-signal may indeed be *small*, if its production is new kind of *hard processes*.

Y.I. Azimov, K. Goeke, & IIS, Phys Rev D **76**, 074013 (**2007**)
CI=**17**

- *Final states* with > **3** particles admit more complicated cases of rescattering interference.



- Example of **4**-particle rescattering interference that may enhance small *Θ*$^+$-contribution (suggested by Amaryan).

Intermediate Summary

- *Interference* of resonances (in energy representation) has same origin as known particle oscillations (in space-time representation).

- Small resonance contribution may be *amplified* & revealed due to its *interference* with high background (*e.g.*, another resonance).

- Manifestation of *interfering* resonance may be very different**:**
  bump, or dip, or **both**; may depend on decay mode.
  Positions of bump/dip are, in general, *shifted* from *true* position of resonance.

- Form of ``resonance'' curve essentially depends on properties of background & on Res-Bkg *relative phase*:
  it may be *symmetric*, or *antisymmetric*, or *strongly asymmetric*.

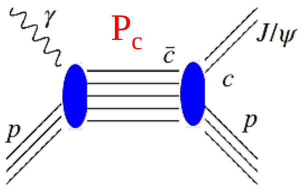
- *Direct interference* is actively used now as important instrument for resonance studies. Some rare decays of well - established resonances are known only due to interference manifestations.

- *Rescattering interference* of resonances may be very useful as well:
  to amplify small resonance signals, especially with new quantum numbers;
  to study production mechanisms of known resonances.

- *Interference of resonances* looks to be worth of more detailed studies, both experimental & theoretical.

Back to Mainstream

Alternative Solution for GlueX J/ψ Data



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**)

CI=2

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

θ & ***ϕ*** are ***J/ψ*** *polar* & *azimuthal* production *angles*.

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

  Using *Landau-Livshitz* normalization

k is *momentum* of photon in CM
J is *total angular momentum*
(2J+1) = **1** for ***S***-wave
= **3** for ***P***-wave

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

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

α is relative *phase shift*

It comes from **fit** of total Xsec

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

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

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

q is *momentum* of vector meson in CM

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

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

M & ***Γ*** are ***mass*** & *energy* ***independent width***
(***P_c*** is too ***narrow***)

- 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***

Γ(γp) & **Γ(J/ψp)**
are *partial decay widths* of
P_c→γp & **P_c→J/ψp**.

How Interference Works

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

CI=18

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

- *Interference* of resonances has same ***quantum nature*** as oscillations of particles, though they are observed in complementary variables – energy (mass) for former, or time for latter.

- *Interference* contribution is linear in both b & R.
  Its relative role depends on R/b.
  @ *small* R/b, *interference* may appear more important than BW contribution itself.
  This can be considered as ***amplification*** of small resonance signal by *interference* with large *background*.

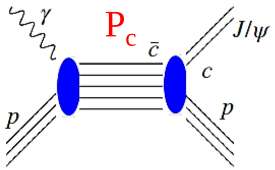
- *Interference* contribution depends on *relative phase* α between b & R.

- *Interference* may be either *positive* (*constructive*) or *negative* (*destructive*).

- In comparison with BW contribution, *interference* may have additional *energy dependence* & may decrease with energy slower than proper BW contribution.

- *Background* itself, b & α, also may depend on energy.
  As a result, *background* may appear different in regions of *constructive* & *destructive interference*, & relative role of these regions may be very different, up to full vanishing of one of them.
  Thus, presence of *interference* may provide either ***bump***, or ***dip***, or ***both***.
  Positions of ***bump*** &/or ***dip*** are, generally, *shifted* from true position of *resonance*.

- Resonances can *interfere* differently in different decay channels, @ least due to different properties of corresponding *backgrounds*.

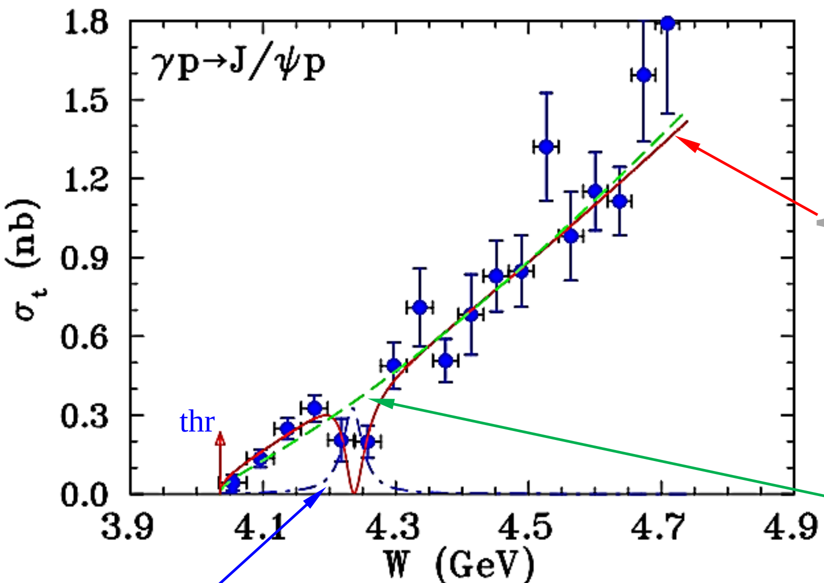


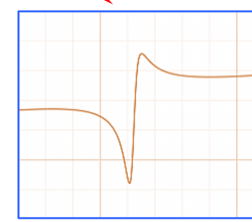
Alternative Solution for GlueX Data

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

- 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**.

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





Resonance: χ^2/ndf=11.99/12=1.00

M= 4235 ±8 MeV
Γ= 35.4±8.2 MeV
X= 0.023±0.005
α= 40.8±5.7 deg

Resolution ~6 MeV

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

No Resonance: χ^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 $\mathbf{P_c(4312)^+}$.
- 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 χ^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 $P_c(4312)^+$.

Cusp Effect

Deciphering Mechanism of Near-Threshold J/ψ Photoproduction

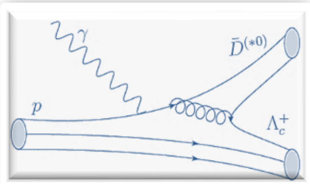
Meng-Lin Du, V. Baru, Feng-Kun Guo, Ch. Hanhart, U.-G. Meissner, A. Nefediev, & IIS, Phys Rev C **106**, 015202 (**2022**)

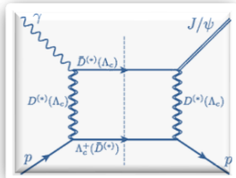
CI=37

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

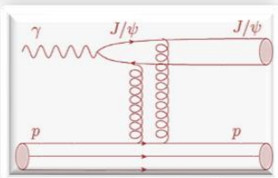
K. Boreskov, A. Capella, A. Kaidalov, & J. Tran Than Van, Phys Rev D **47**, 919 (**1993**)

- Cusp effect is visible & in agreement with GlueX

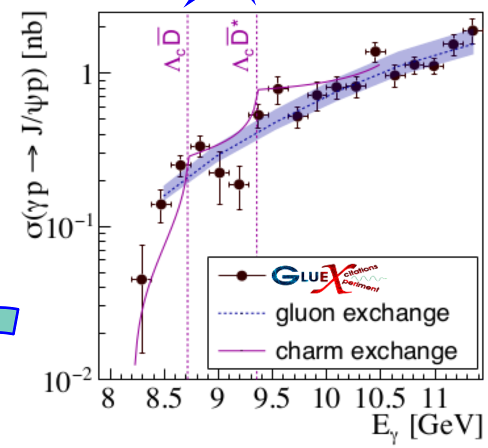




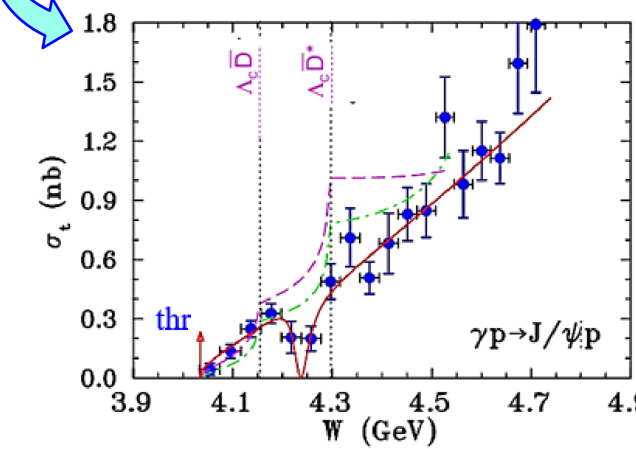
- $c\bar{c}$ *pair* is produced by ***1g*** & interacts with *proton*.



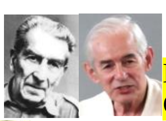
- $c\bar{c}$ *pair* is produced by ***photon*** via *VMD* & interacts with ***proton*** through *2g* exchange.



- 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**

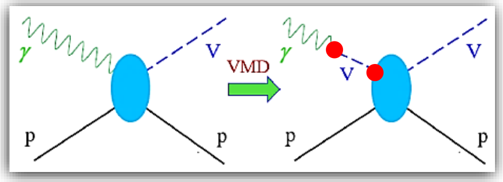
Vector Meson – Nucleon

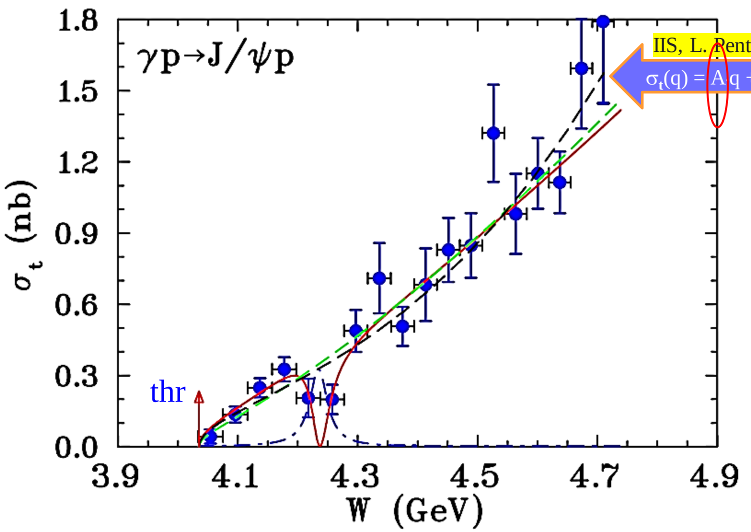
Scattering Length

Joint HEPD-THD Seminars (Thursdays) April 6, 2023

Vector Meson – Nucleon SL

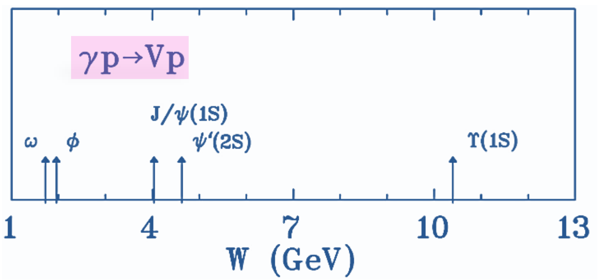
- Due to ***small size*** of "*young*" *V* vs "*old*" *V*, measured & predicted *SL* is very small.
- *V* created by photon @ threshold then most probably *V* is not formed completely & its radius is smaller than that for normal ("*old*") *V*.
- Therefore, one observes stronger suppression for ***Vp***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

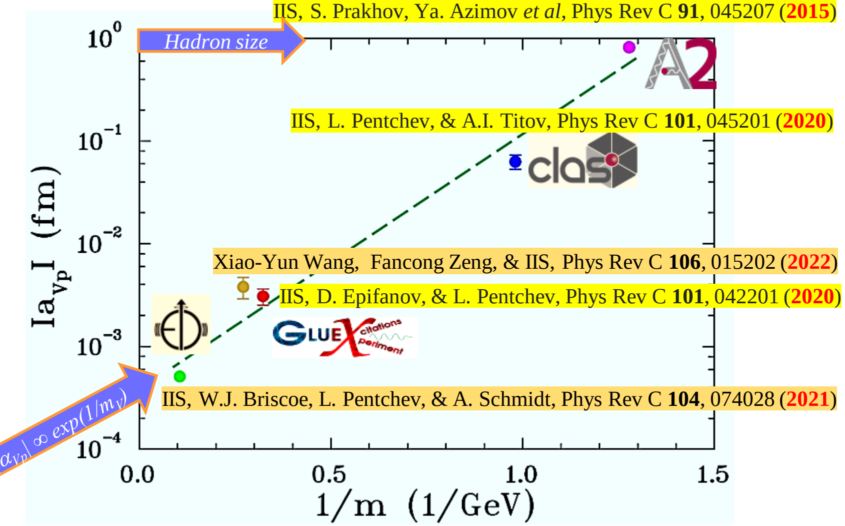




	A [nb/MeV/c]	$|a_{J/\psi p}|$ [mfm]
2019	0.46±0.16	3.08±0.55±0.42
2023	0.43±0.10	2.88±0.34

GlueX

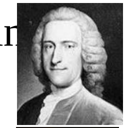




- $p \to V$ coupling $\bar{q}q$ is proportional to α_s & *separation* of corresponding quarks.
- This *separation* (in *zero approximation*) is proportional to $1/m_V$.

JPAC Contribution


- Originally *PWA* arose as technology to determine amplitude of reaction via fitting scattering data.
  - ⇒ That is *non-trivial mathematical problem* – looking for solution of ill-posed problem following to Hadamard & Tikhonov. [number of equations less than number of unknown quantities]
  - ⇒ There are two main technologies to look for solution:
    (i) ***least-squares minimization*** of functions which are linear i unknown parameters, χ^2 &
    (ii) *likelihood measures goodness* of fit of statistical model.
    [***Minimizing*** χ^2 is equivalent to *maximizing* (log) likelihood just case *not small statistics*]
  - ⇒ Model *independent* treatment or data *driven* treatment.

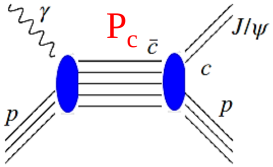


Roger Cotes

Sir Ronald Aylmer Fisher

- Resonances appeared as by-product [bound states objects with definite quantum numbers, mass, lifetime, & so on].

- Standard PWA
  - ⇒ Reveals only wide Resonances, but not too wide (**Γ** < 500 MeV) & possessing not too small BR (BR > 4%).
  - ⇒ Tends (by construction) to miss narrow Resonances with **Γ** < 20 MeV.



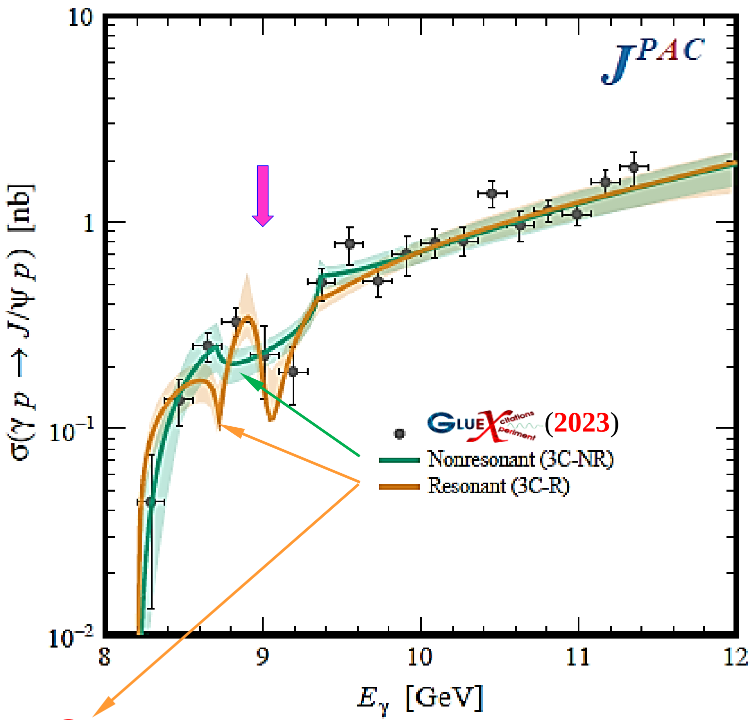
J^{PAC} for J/ψ Photoproduction

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

CI=4

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

- *Global fit of both Hall C & D $d\sigma/dt(t)$ & Hall D $\sigma_{tot}(E_\gamma)$*
  - (1C) $J/\psi p$ interaction
  - (2C) J/ψ 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)**



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

Pole position
(no uncertainties)
M = **4211** MeV
Γ = **48** MeV

⇒ **101** MeV below LHCb
24 MeV below us

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).

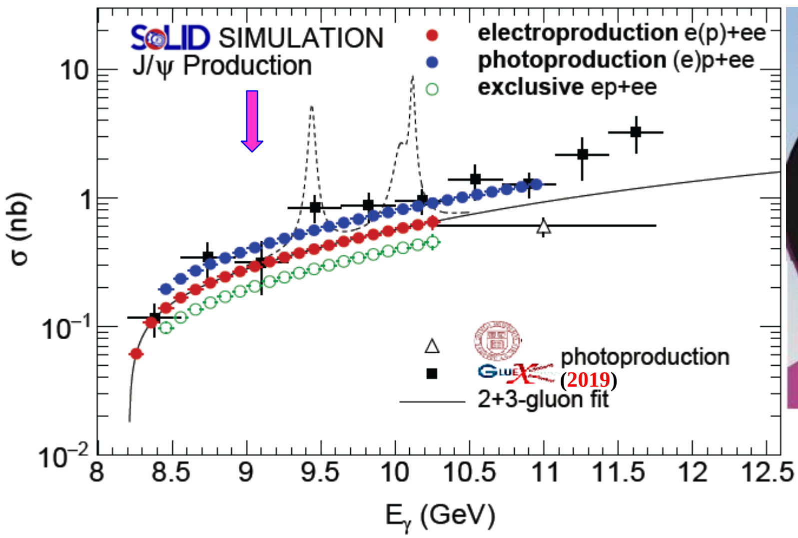
- Precise measurements critically important to disentangle *reaction mechanism* @ threshold.

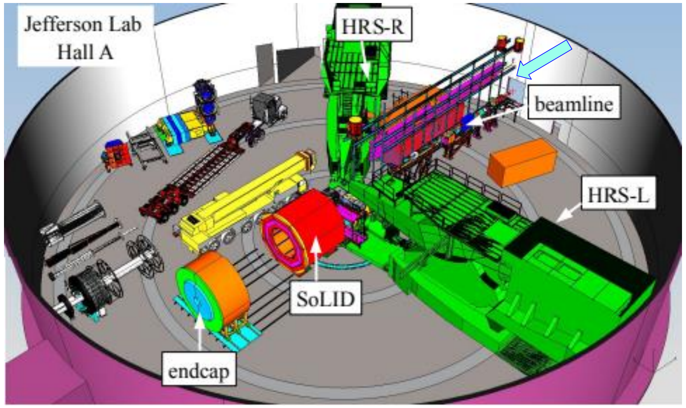
SOLID Contribution

SoLID

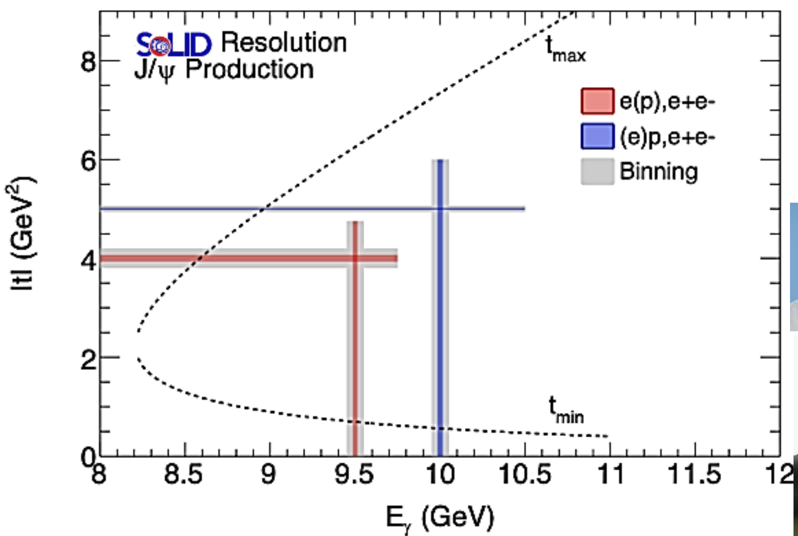
Hall A for more J/ψ Photoproduction

Bump Hunting





- *Nominal luminosity* for SoLID -J/ψ is **50** days @ **10^{37}** cm^{-2} s^{-1}



J. Arrington *et al*, arXiv:**2209**.13357 [nucl-ex]

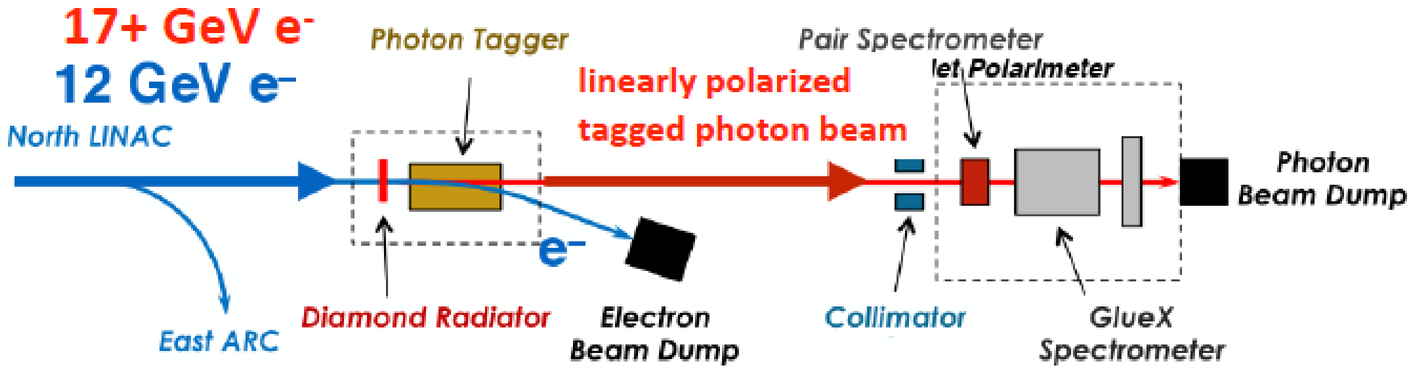
- Only downside is we, probably, must wait **10** years for such results.

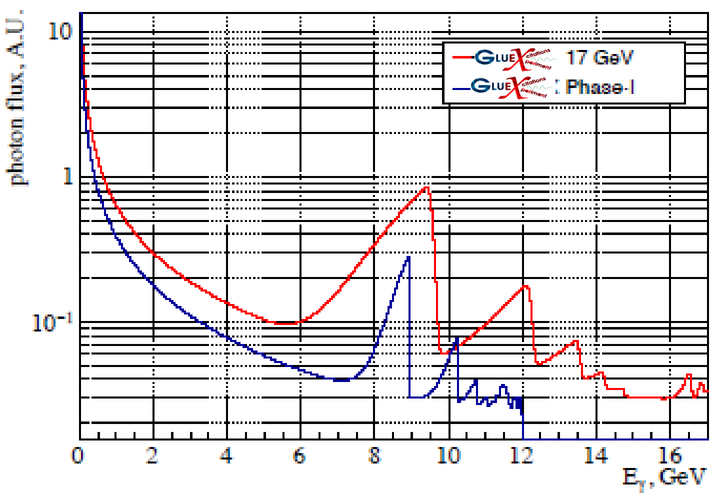
JLab at High Energies

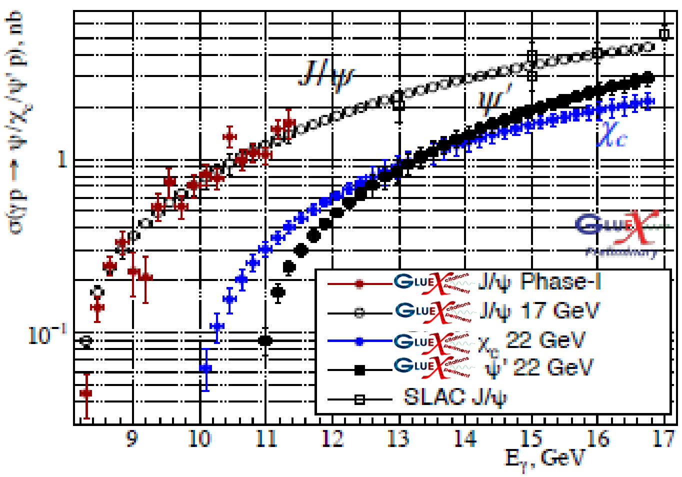
Jefferson Lab

A. Accardi *et al*, arXiv:2306.09360 [nucl-ex]

Hall D Apparatus with 17+ GeV electron beam







- Moving end point from 12 GeV to 17+ GeV:
  - higher flux (and polarization) toward higher energies, while low energies less affected (no load on detectors)

Courtesy of Lubomir Pentchev, 2023

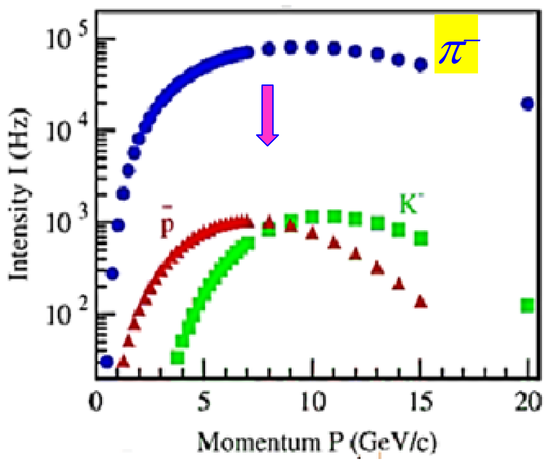
J-PARC Contribution

Bump Hunting

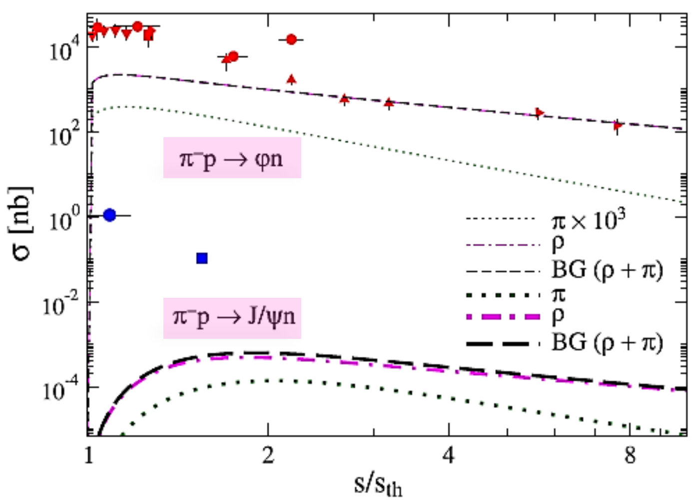
for $\pi^- p \to J/\psi\, p$

High-p Proposal, J-PARC, **2023**

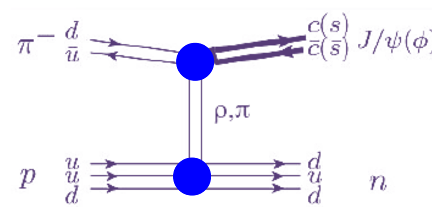
Hidden Charm Production by ***High-p*** *Experiment*



- *High-p* plans to detect **J/ψ** to e^+e^- & $\mu^+\mu^-$ pairs using **E50** spectrometer.
- *High-p* can use incident **P** = **2 – 20** GeV/c beam from **π20** beamline.
- One can measure **J/ψ** 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**%.

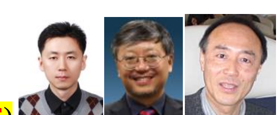


10^6 $g_{\phi\rho\pi} > g_{J/\psi\rho\pi}$



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

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



STAY TUNED

Summary

SUMMARY

- Interpretations of published LHCb & GlueX cases considered *constructive interference* between resonance & non-resonant background for particular PW,
  In this work, we relax this requirement & consider & possibility of *destructive interference which nobody did before*.

- Here we have shown that *resonance-like* structure is "*plausible*" in new GlueX data, in energy region close to low-mass LHCb *pentaquark*.

- Statistics of new GlueX data is not sufficient to draw definite conclusion.

- Predictions of *open charm* model reasonably agree with new GlueX data.
  Interference between *open charm* & *gluon exchange* may (by some accident) produce ***dip*** but there is room for *resonance*.

  While not evident in GlueX data, one cannot exclude that we have all **4** LHCb P_c resonances together with *open charm* & *gluon exchange* (*gluon* contribution can be strongly suppressed due to "*young*" effect).

- It seems that analysis of full GlueX-I & GlueX-II &/or SoLID may help.
  It will be good to shrink significantly *uncertainties* (to increase statistics by a factor of **10+**) & make much larger number of cross sections (by factor of **2+**).
  Polarized measurements are important contribution for model independent PWA.

- J-PARC may help to solve this puzzle.

Thanks

igor@gwu.edu