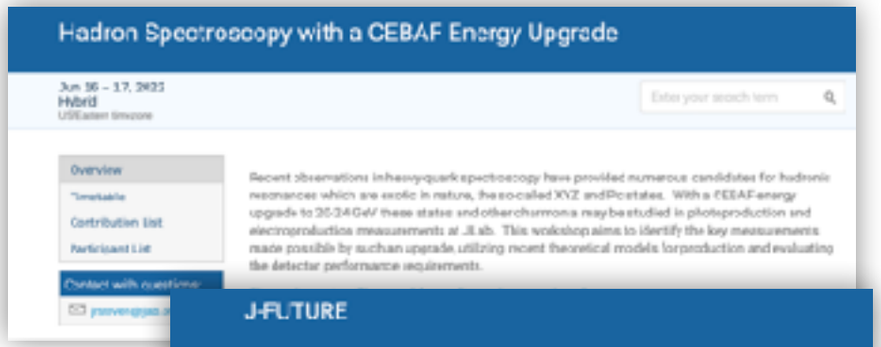
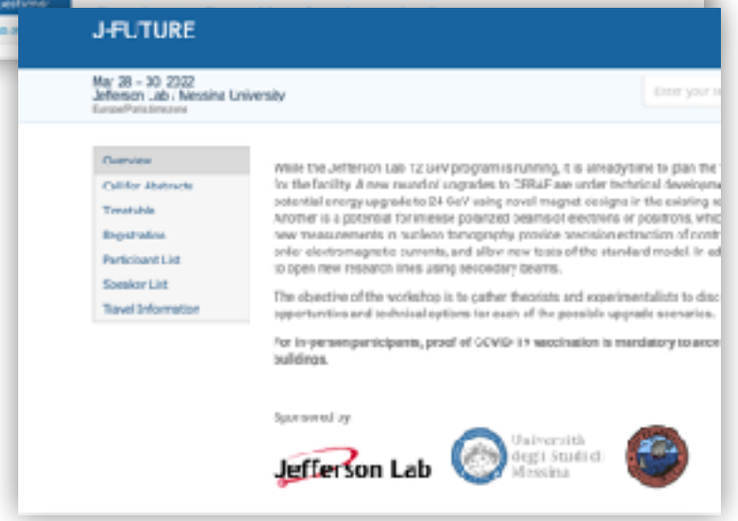
Charmonium Photo-production

Adam Szczepaniak (IU/JLab)





- It's new: no XYZ state has been uncontroversially seen so far. Scarce consistency between various production mechanisms
- Potentially free from re-scattering effects that could mimic resonances in multi-body decays (e.g. triangles)
- The framework is (relatively) clean from a theory point of view
- The local probe (photon) offers another way of exploring nature of the states
  - Several workshops over the past 18months to explore opportunities for XYZP physics with photon/electron beams.
  - This talk: expectations, simulation results and some recent results

Happy 10y anniversary JPAC'ers

Misha

Cesar

Daniel

Viktor

Sergi

Jorge

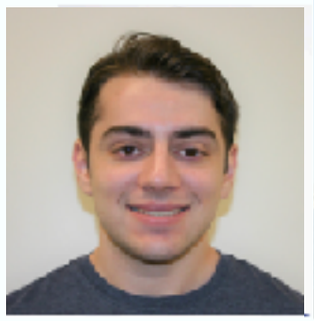
Kevin

Alessandro

Lukasz

Astrid

Vincent



Wyatt

Adam

Gloria

Miguel

Andrew

Emilie

Akaki

Emmanuel

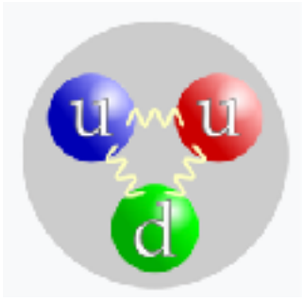
Robert

Sebastian

André Petermann Murray Gell-Mann George Zweig

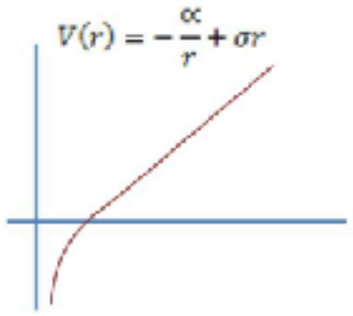
Petrov, V,A. "Half a Century with Quarks". arXiv:1412.8681

Hadrons

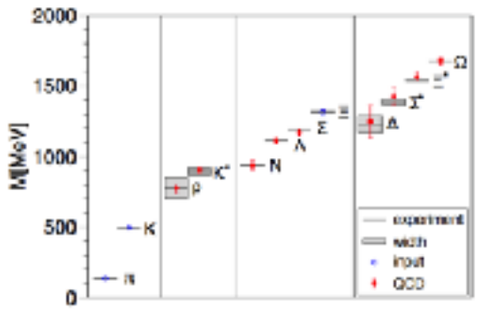


Nuclei

he Nobel Prize in Physics 1963. NobelPrize.org. Nobel Prize Outreach AB 2022. Sat. 17 Sep 2022.

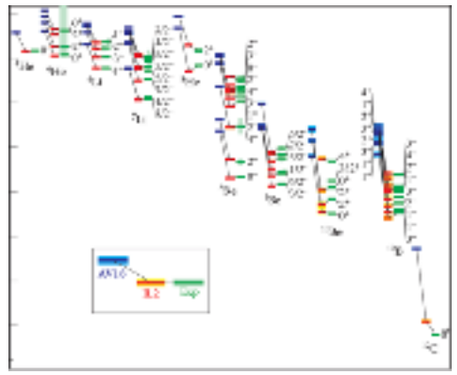


E.Echten et al. Phys. Rev. Lett. 34, 369 (1978)

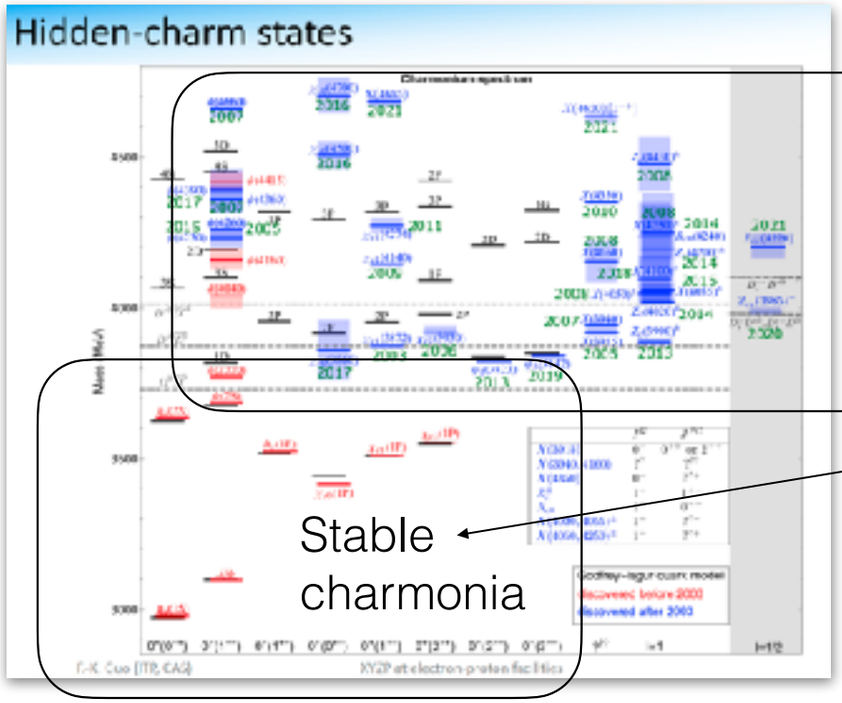


S. Durr et al., Science 322, 1224 (2008)

R. Machleidt,D.R. Entem, PhysRep, 503,1 (2011)



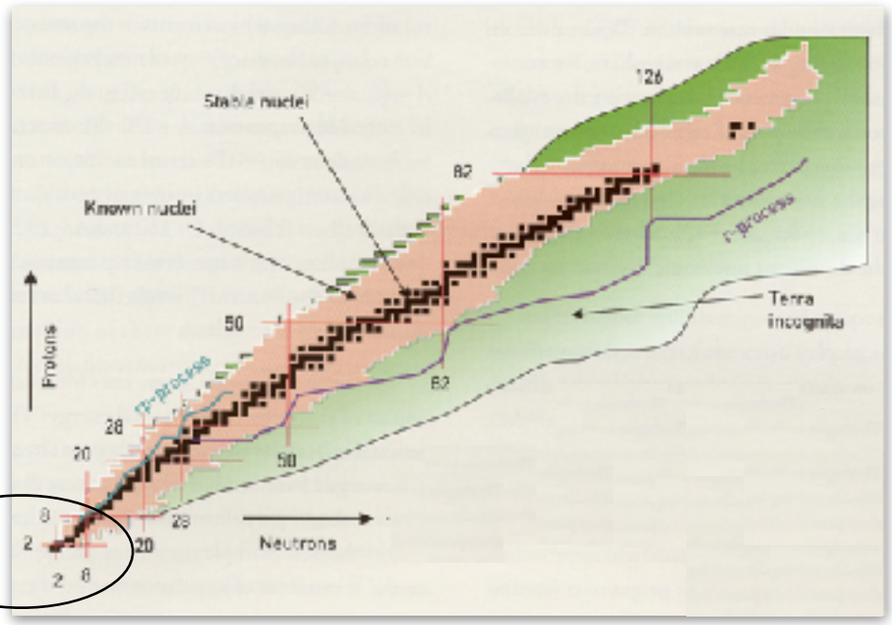
D.Dean, Physics Today 60, 11, 48 (2007)



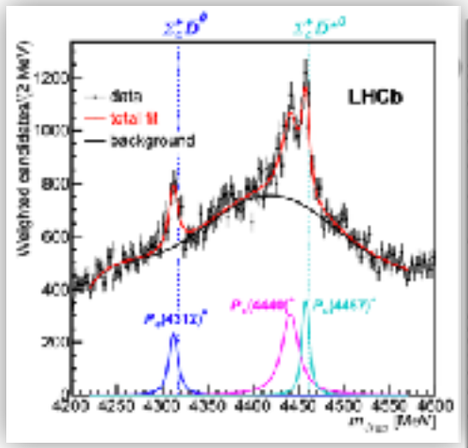
F-K.Guo

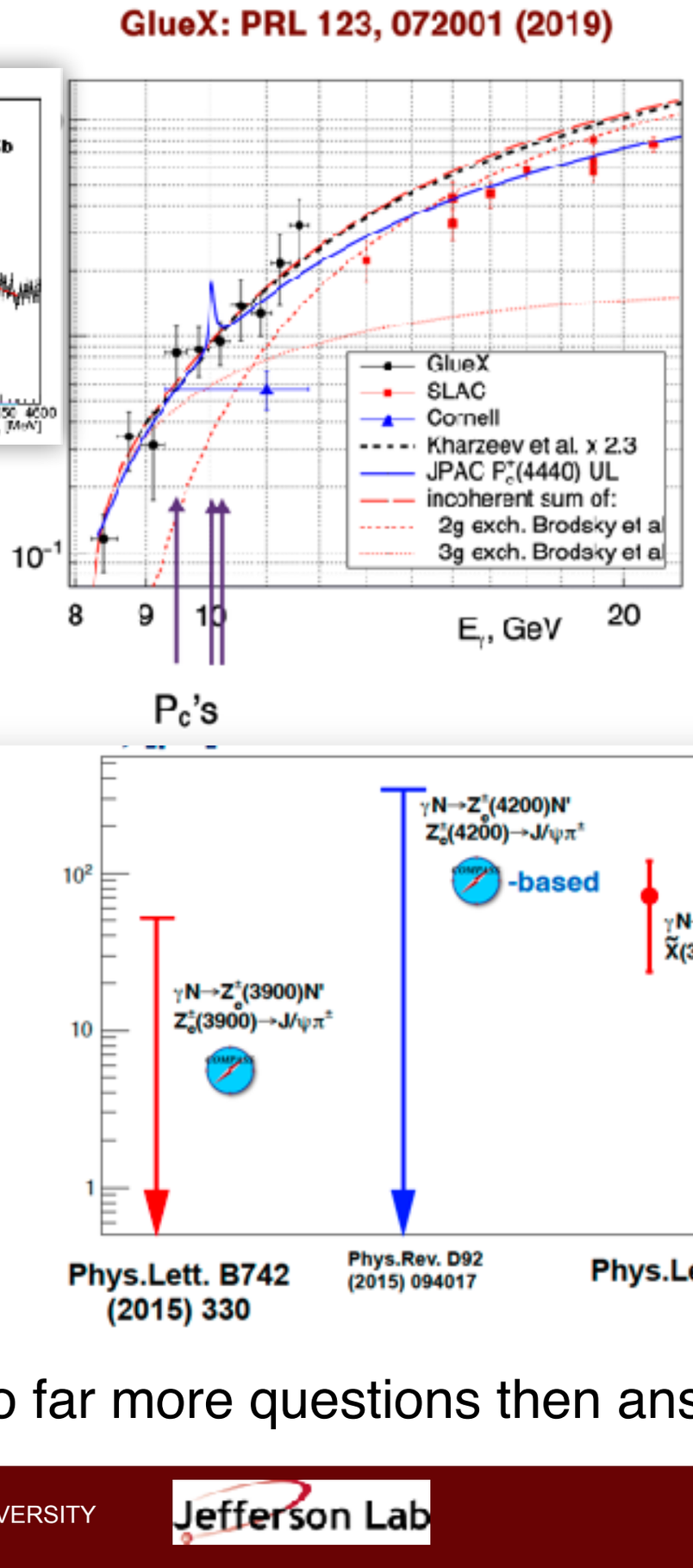
Terra incognita

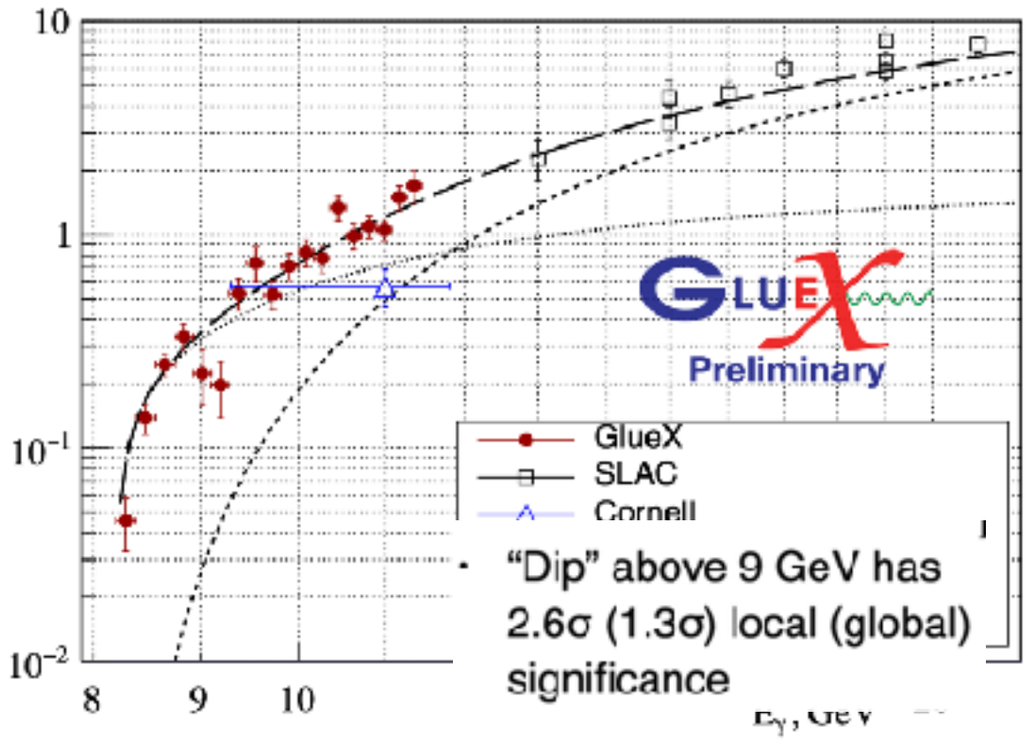
- Are these analogs of compact, halo, Borromean, etc.



Pc , X's, Z's ….



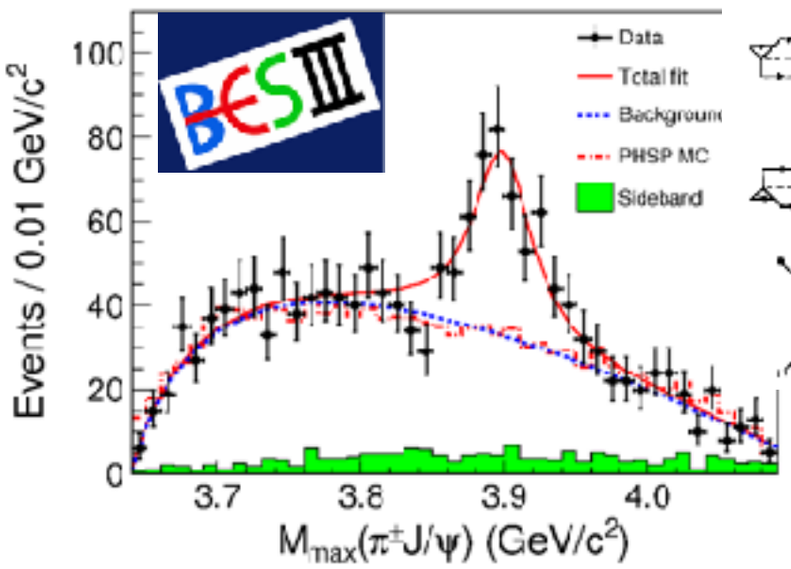




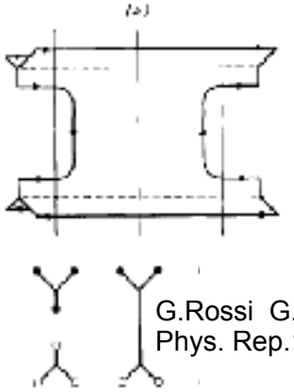
Threshold effects ? Du et al, EPJC 80, 1053 (2020)

- So far more questions then answers

What are the Z's?



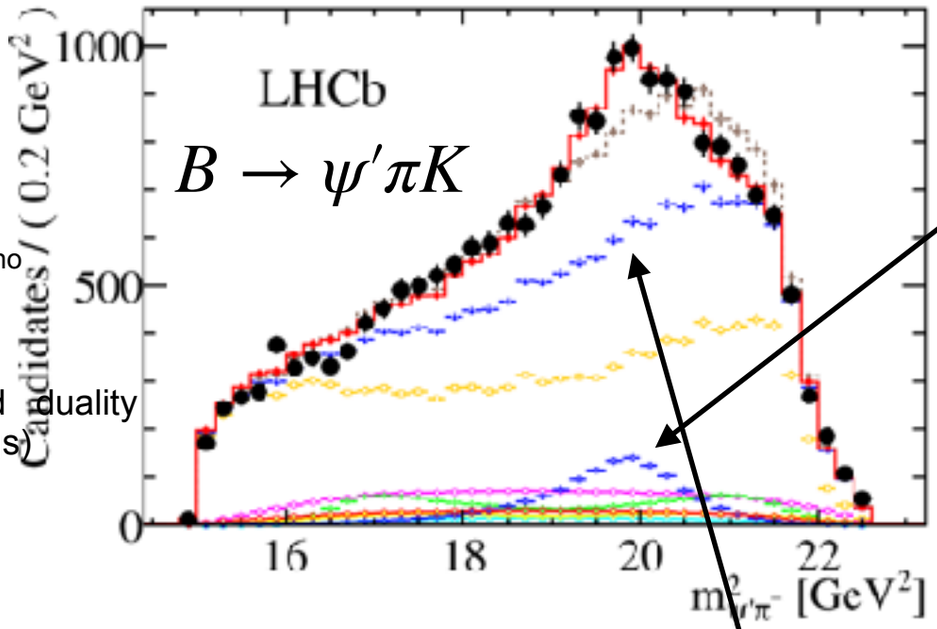
$$e^+e^- \to Y \to J/\psi\pi^+\pi^-$$



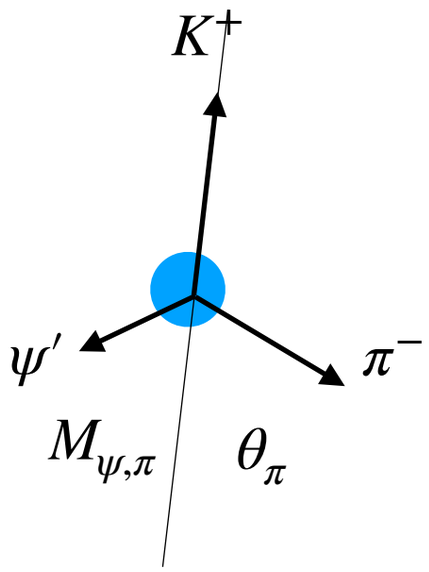
G.Rossi G. Veneziano
Phys. Rep.1982

Muti quark states and duality
(large-N_c, QCD strings)

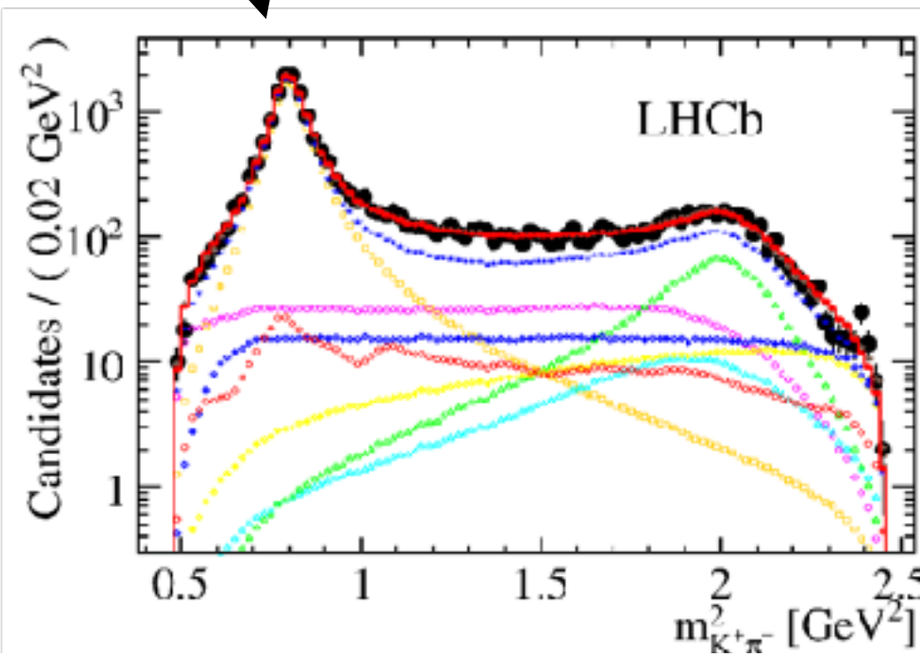
Are the Z's true resonances or kinematic effects



Kinematic effects from K* decays ?



$$B \to \begin{cases} K^{*0}\psi' \to \pi^- K^+\psi' \\ Z^- K^+ \to \psi'\pi^- K^+ \end{cases}$$



Need for complete amplitude analysis

$Z_{c,b}^{+}$ Production @JLab++, EIC

M. Albaladejo et al. [JPAC], PRD (2020)
D.Winney et al. (JPAC) .

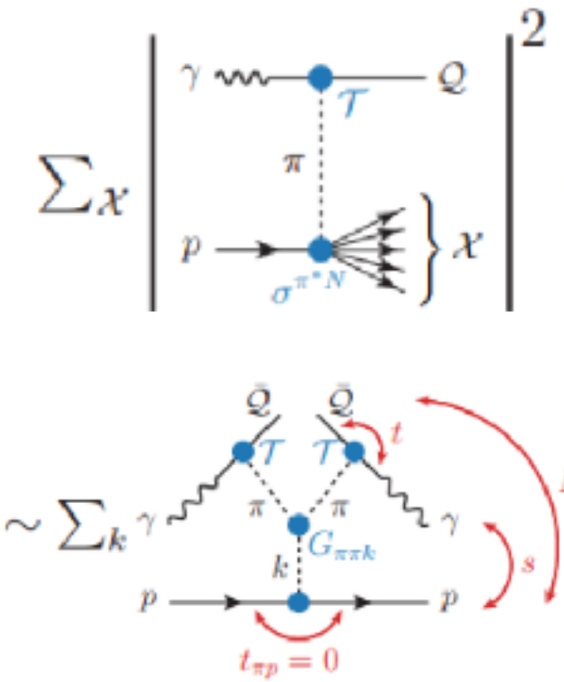


TABLE II. Summary of results for production of some states of interest at the EIC electron and proton beam momentum $5 \times 100(GeV/c)$ (for electron x proton). Columns show : the meson name; our estimate of the total cross section; production rate per day, assuming a luminosity of 6.1×10^{33} $cm^{-2}s^{-1}$; the decay branch to a particular measurable final state; its ratio; the rate per day of the meson decaying to the given final state.

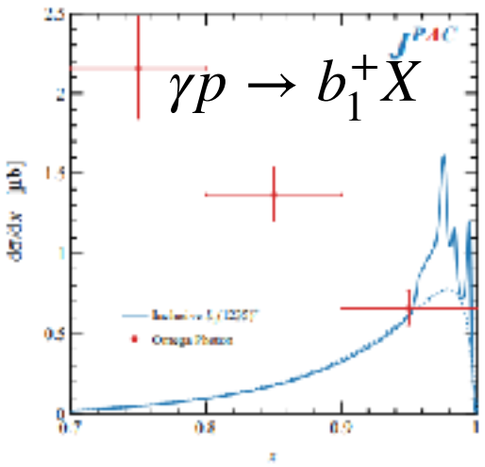
Meson	Cross Section (nb)	Production rate (per day)	Decay Branch	Branch Ratio (%)	Events (per day)
$\chi_{c1}(3872)$	2.3	2.0 M	$J/\Psi\ \pi^+\pi^-$	5	6.1 k
$Y(4260)$	2.3	2.0 M	$J/\Psi\ \pi^+\pi^-$	1	1.2 k
$Z_c(3900)$	0.3	0.26 M	$J/\Psi\ \pi^+$	10	1.6 k
$X(6900)$	0.015	0.013 M	$J/\Psi\ J/\Psi$	100	46
$Z_{cs}(4000)$	0.23	0.20 M	$J/\Psi\ K^+$	10	1.2 k
$Z_b(10610)$	0.04	0.034 M	$\Upsilon(2S)\ \pi^+$	3.6	24

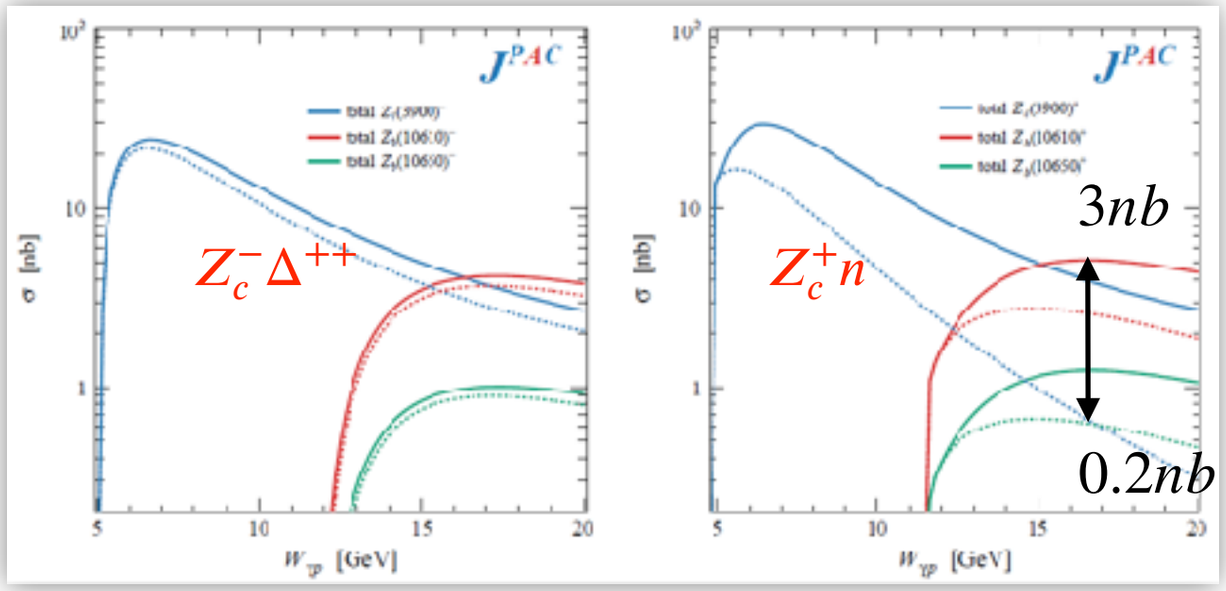
C++ code available online (D. Winney)

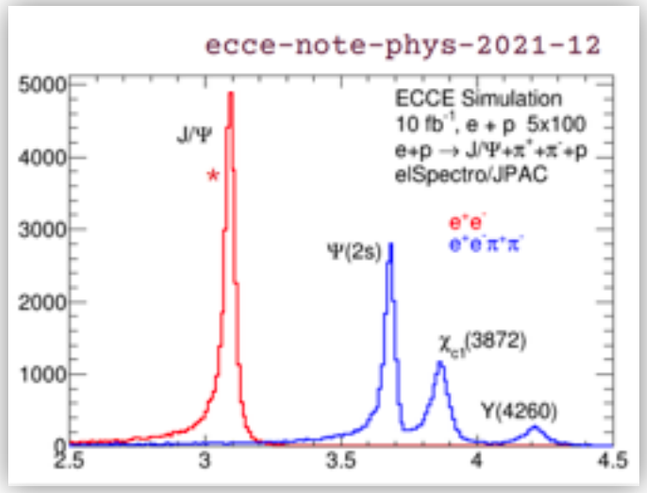
Implementation in simulation with El-Spectro (D. Glazier)

- Couplings from data as much as possible, not relying on the nature of XYZ
- The model is expected to hold in the highest x- bin
- Model underestimates lower bins, conservative estimates

https://github.com/dwinney/jpacPhoto

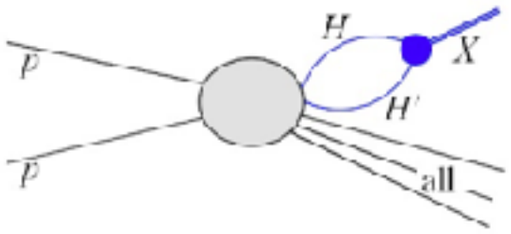






- Production at EIC

Artoisenet, Braaten, PRD83(2011)014019; FKG, Meißner, W. Wang, Z. Yang, EPJC74(2014)3063



$\sigma(pp/\bar{p}\to X)$ [nb] Exp.		Λ=0.5 GeV	Λ=1.0 GeV
Tevatron	37-115	7 (5)	29 (20)
LHC-7	13-39	13 (4)	55 (15)

Albaladejo, FKG, Hanhart et al., CPC41(2017)121001

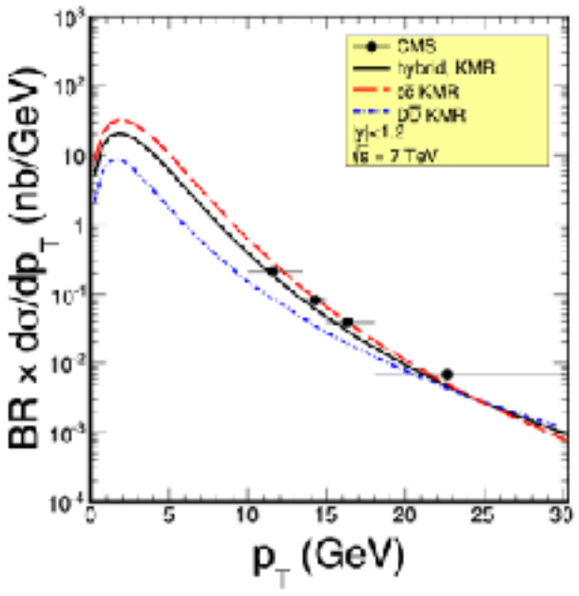
- Order-of-magnitude estimates of the semi-inclusive electro-production of hidden/double-charm hadronic molecules (in units of pb)

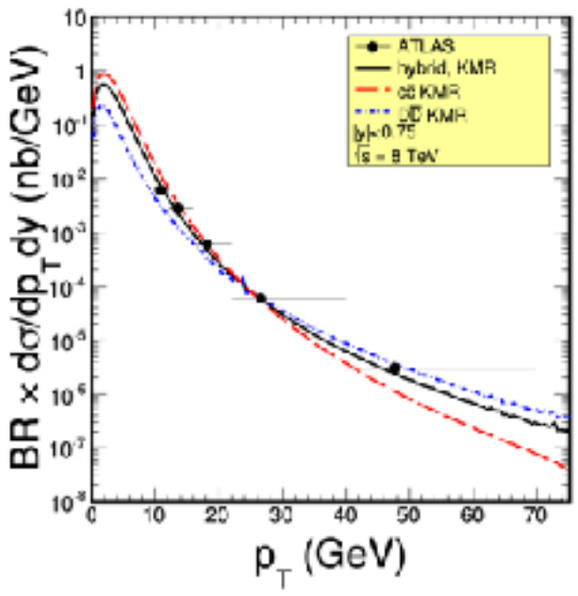
	Constituents	$I,J^{P(C)}$	EicC	EIC
$X(3872)$	$D\bar{D}^*$	$0,1^{++}$	21(89)	216(904)
$Z_c(3900)^0$	$D\bar{D}^*$	$1,1^{+-}$	0.4×10^3 (1.3×10^3)	3.8×10^3 (14×10^3)
Z_{cs}^-	$D^{*0}D_s^-$	$1/2,1^+$	19(69)	250(900)
$P_c(4312)$	$\Sigma_c\bar{D}$	$1/2,1/2^-$	0.8(4.1)	15(73)
$P_{cs}(4338)$	$\Xi_c\bar{D}$	$0,1/2^-$	0.1(1.6)	1.8 (30)
Predicted	$\Lambda_c\bar{\Lambda}_c$	$0,0^{-+}$	0.3 (3.0)	10 (110)
Predicted	$\Lambda_c\bar{\Sigma}_c$	$1,0^-$	0.01 (0.12)	0.5 (5.5)
T_{cc}^+	DD^*	$0,1^+$	0.3×10^{-3} (1.2×10^{-3})	0.1 (0.5)

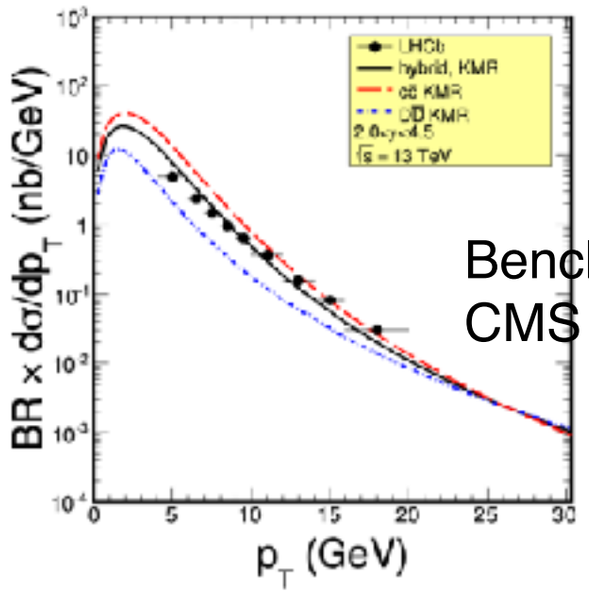
F-K Guo @ EIC Workshop

- Production at EIC

$$|X(3782)\rangle = \alpha|c\bar{c}\rangle + \frac{\beta}{\sqrt{2}}\left(|D\bar{D}^*\rangle + |\bar{D}D^*\rangle\right)$$







Benchmark at on CMS data

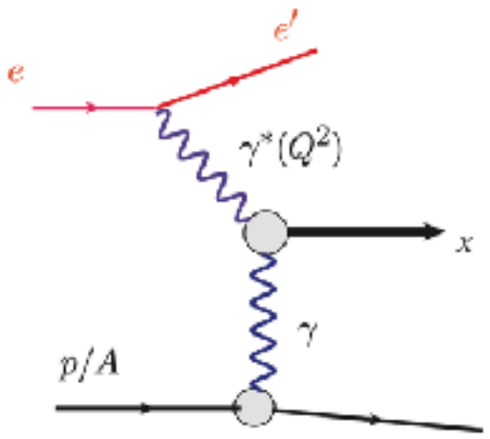


Table: Cross sections on proton and ^{208}Pb

$\sqrt{s_{eN}}$ [GeV]	$\sigma(ep \to epX)$ [pb]	$\sigma(eA \to eAX)$ [pb]
50	0.06	60
140	0.16	340

W. Schaefer @ EIC Workshop

J/ψ photoproduction near threshold

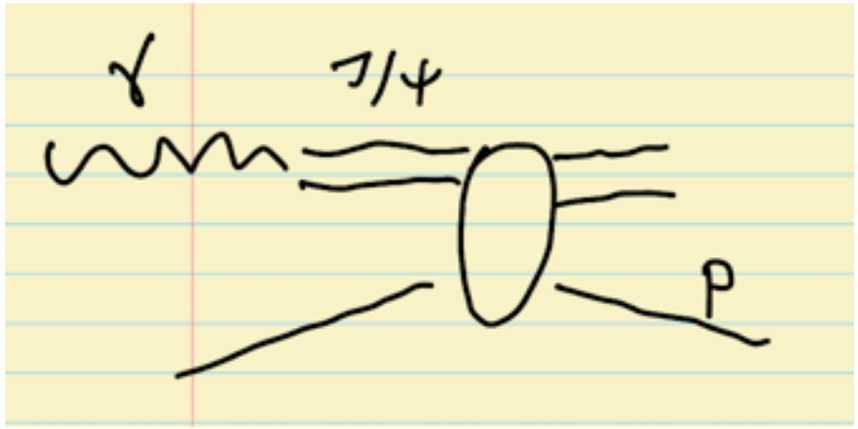
- Heavy vector quarkonium near threshold possibly relevant for extracting unexplored nucleon properties (mass radius, gravitational form factors, etc.)
- Signal channel also contains hidden-charm pentaquark candidates seen at LHCb.
- Abundance of new data coming from Jefferson Lab on energy and angular dependence of x-section.

GlueX [arXiv:2304.03845]

J/ψ-007 [Nature 615 (2023) 7954, 813-816]

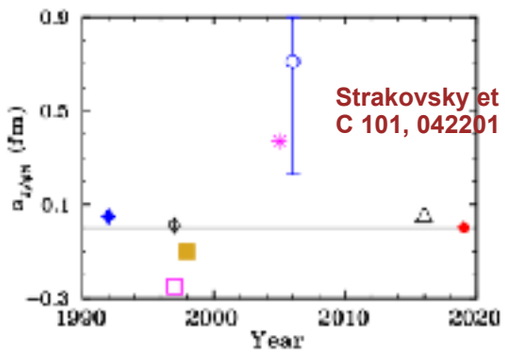
J/ψ near threshold

- VMD (is a specific production model)



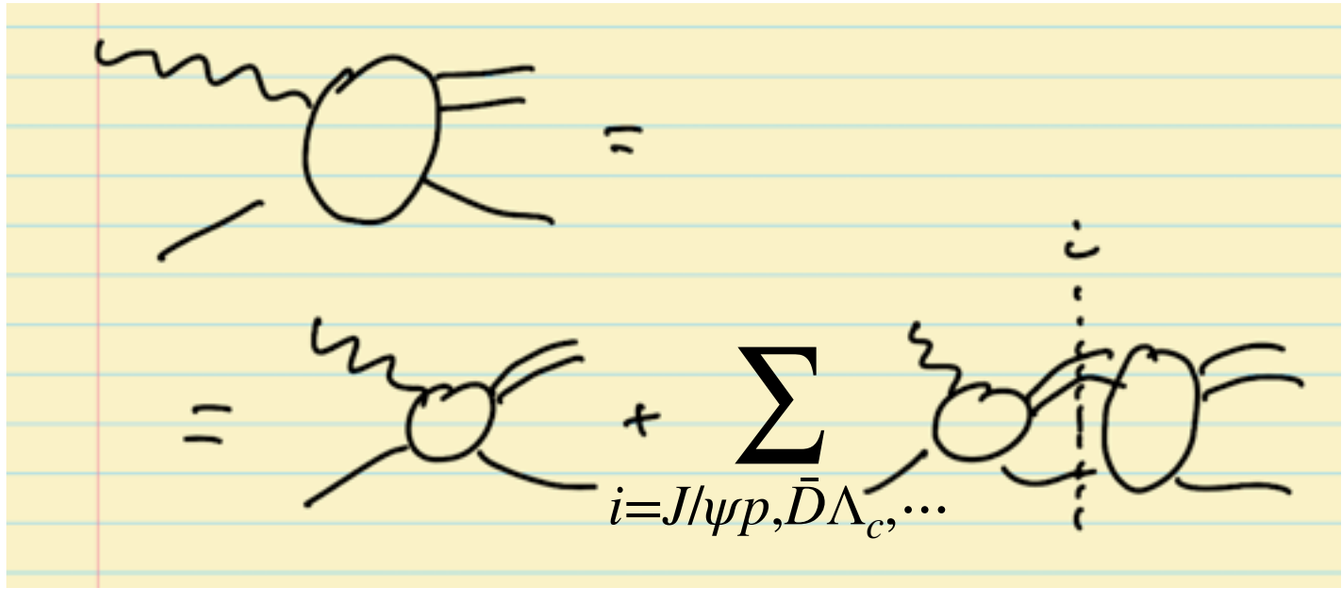
$$T_{\gamma p\to\psi p} \propto \left(\frac{ef}{m_\psi}\right)(8\pi E_{th})a_S$$

ψp scattering length



Strakovsky et al [Phys. Rev. C 101, 042201 (2020)]

- In general



$$T_{\gamma p\to\psi p} \propto (8\pi E_{th})r_{\gamma p\psi p}(1 - ia_S k_f + O(k_f^2))$$

Range of $c\bar{c}$ photo-production

x-section @ threshold determines $r_{\gamma p\psi p}$

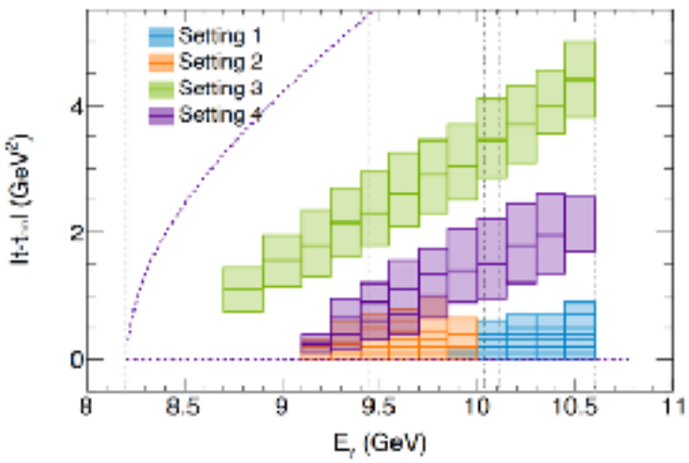
while energy dependents gives a_S

J/ψ photoproduction near threshold

- Fit energy and mom-transfer using s-channel partial waves

$$\frac{d\sigma}{d\Omega} = \frac{1}{64\pi^2 s}\left(\frac{k_f}{k_i}\right)|T_{\gamma p\to\psi p}(s,\theta)|^2$$

$$T_{\gamma p\to\psi p}(s,\theta) = \sum_{l=0}^{l_{max}}(2l+1)T_l(s)P_l(\theta)$$



- Since $T_l(s) \sim (k_i k_f R^2)^l$ convergences requires $(k_i k_f R^2) < 1$

We find $k_f k_i R^2 \leq 1$ for $E_\gamma \sim 20GeV$

- Determine $r_{\gamma p\psi p}$ and a_S from normalization and energy dependence

  - Generalizations :
    - Coupled channels $\bar{D}^{0(*)}\Lambda_c^+$ Du et al [Eur. Phys. J. C 80 (2020) 1053]
    - Extension of effective Range $K_l(s) = k_f^{2l}(a + bk_f^2 + \cdots)$
    - Statistical analysis

Fit results/conclusions

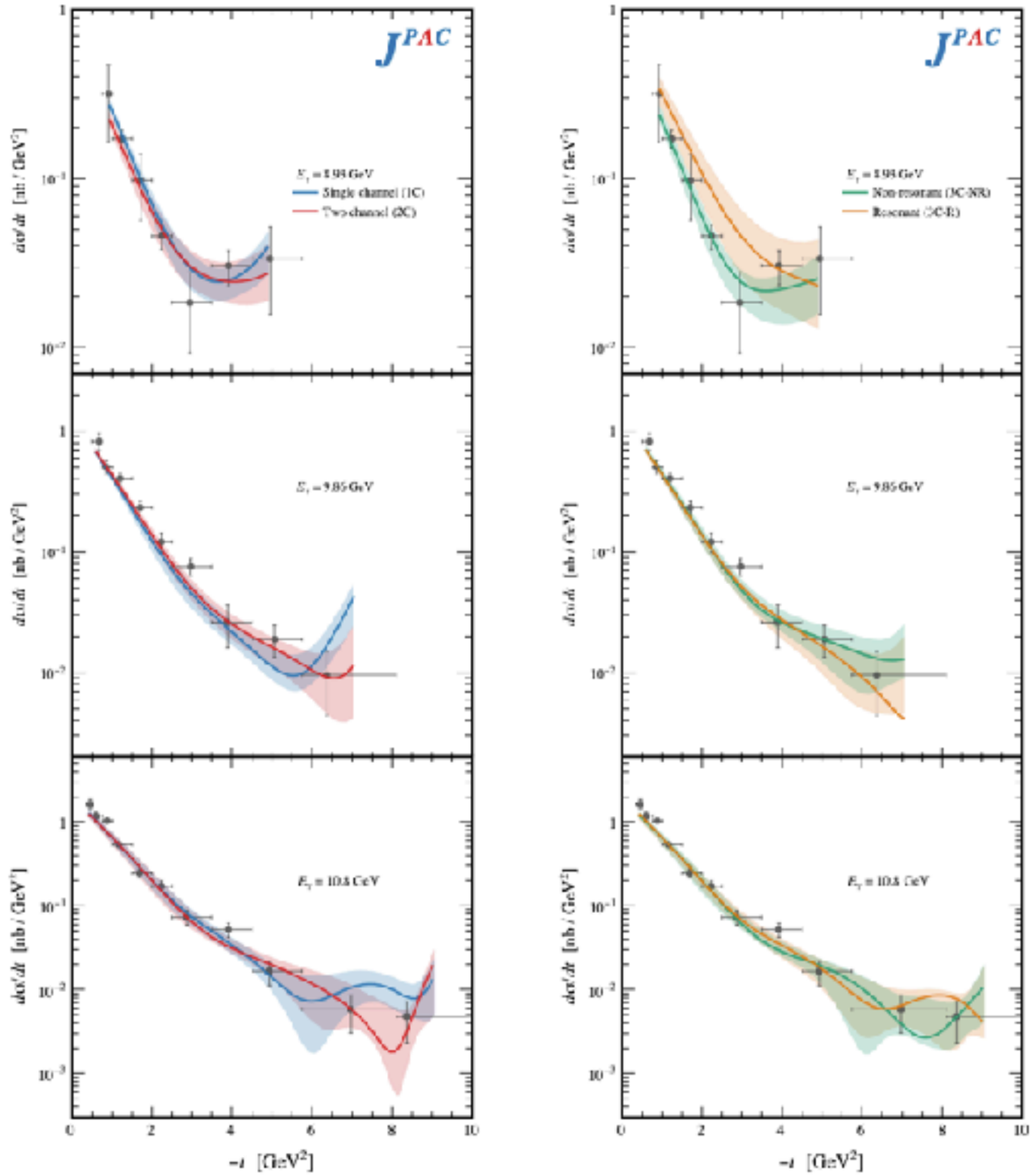


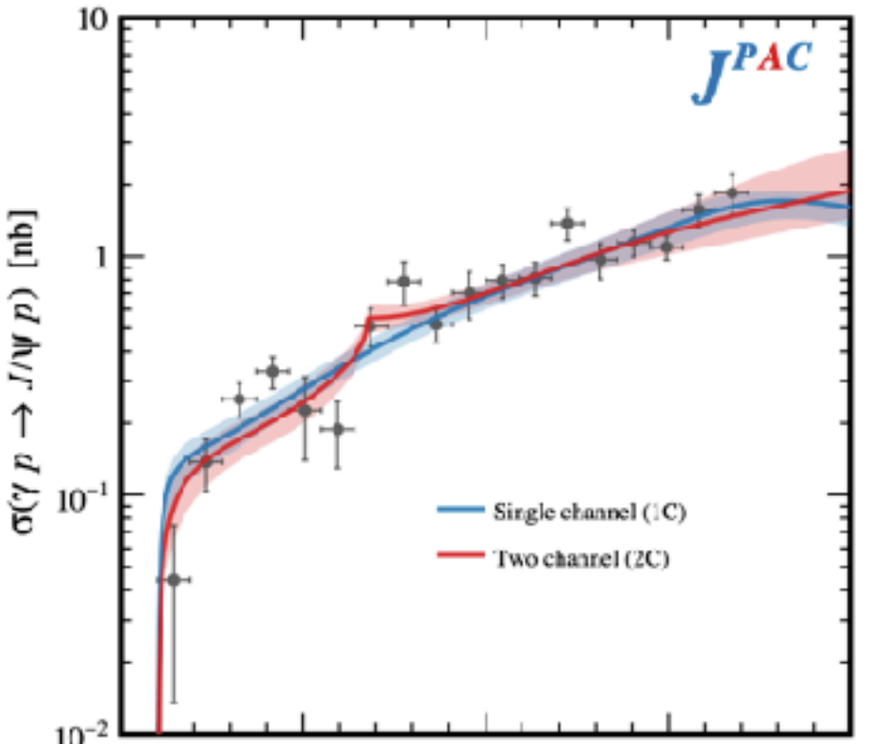
FIG. 2: Fit results for the differential cross section compared to GlueX data from [37]. The bands correspond to the 1σ uncertainties from the bootstrap analysis.

- Angular dependence saturated by the lowest partial waves

$$l_{max} \leq 3$$

- The expected hierarchy of partial waves S>P>D>F with the flattening at larger-t accounted for by p.w interferences

Fit results/conclusions



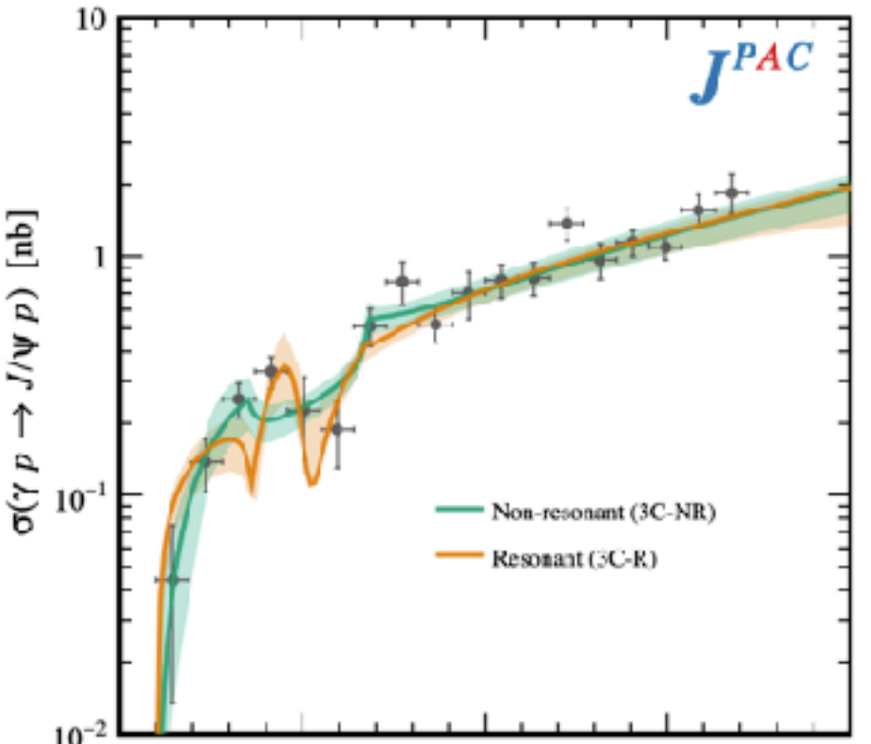
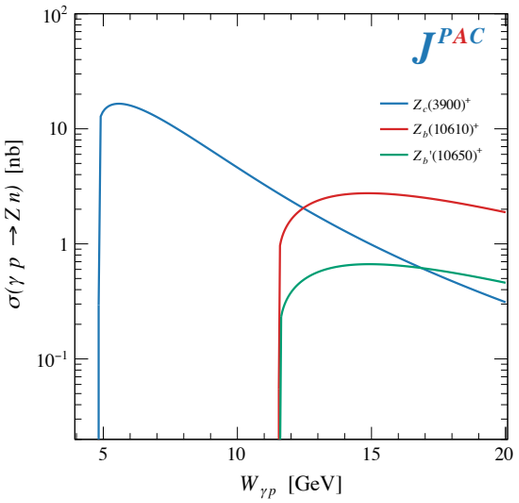


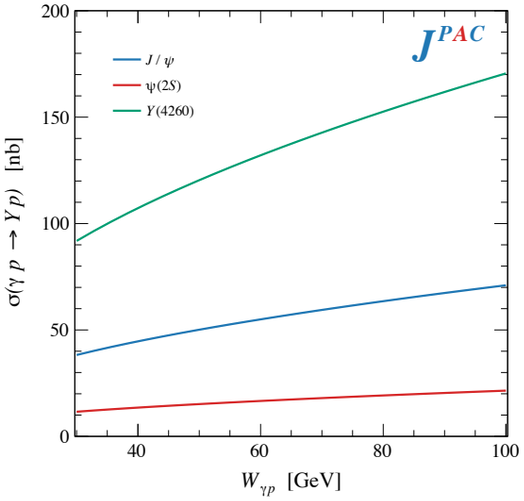
FIG. 1: Fit results for the integrated cross section compared to GlueX data from [37]. Bands correspond to 1σ uncertainties from bootstrap analysis.

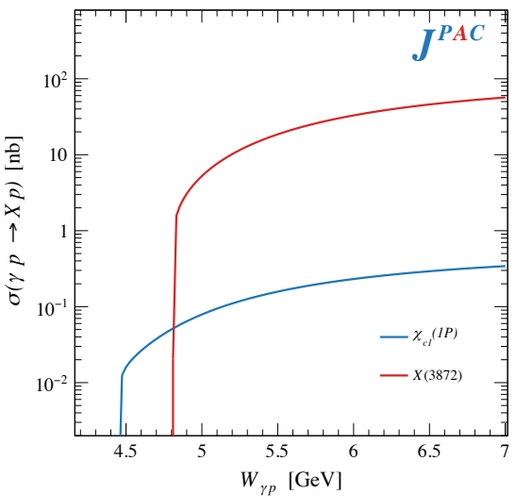
- Elastic $\psi p \to \psi p$ scattering length $a_S \sim O(0.1fm)$ found incompatible with VMD expectations (albeit with large errors)
- Inclusion of open charm reduces the discrepancy

- Fits also suggests relevance of open charm production and not incompatible with pentaquark production Du et al [Eur. Phys. J. C 80 (2020) 1053]
- Need more precise data, including open charm production

Summary







- XYZ, exotic hadron spectroscopy is the new terra incognita of QCD.
- At EIC/JLab++ yields are expected to be comparable to e^+e^- colliders at ~10^{34} (higher luminosity, lower energy) and triggers optimized for charmonium final states;
- Direct production vs indirect (BESIII, Belle, LHCb) which involve more complicated final states, particularly true for the Z's which so far seen only in 3body final states. Null results are as important as observations !
- Variable photon energy is important, it probes different production mechanisms : Y production at higher energies W>10 GeV, XZc , at lower W < 10 GeV
- Simulations and theory work underway, need to further develop the work force

https://github.com/dwinney/jpacPhoto