The Joint Physics Analysis Center and its role in Hadron Spectroscopy Analysis

Adam Szczepaniak (IU/JLab)

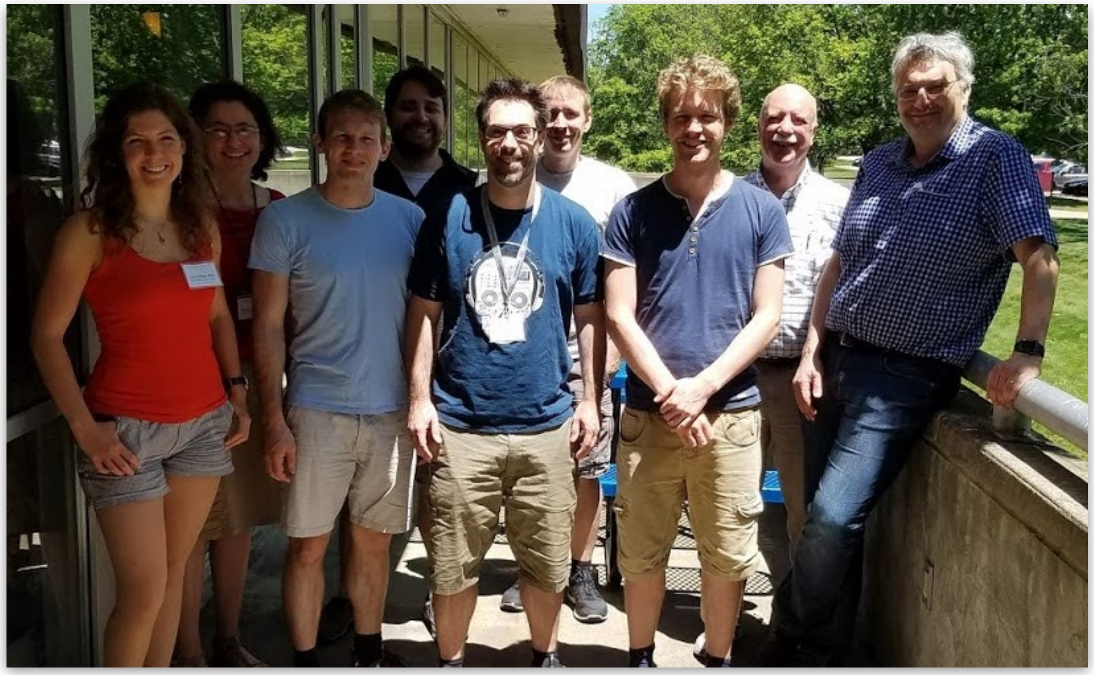
Andrew Jackura

Old Dominion University

- History and People of JPAC
- A few (earlier) results: for new results I invite you to the parallel sessions
- Future directions and opportunities

Brief history

JPAC ca. 2018



- Established in 2013 to develop theory and phenomenology in support of experimental program at JLab12.

- Bridge faculty (Emilie Passemar) postdocs, Vincent Mathieu, Igor Danilkin, Cesar Fernandez-Ramirez.

Emilie Passemar

Indiana University

César Fernández Ramírez

UNAM

Igor Danilkin

JGU Mainz

Vincent Mathieu

University of Barcelona

The Collaboration

Full Members

Adam Szczepaniak
Indiana University

Alessandro Pilloni
Università di Messina

Arkaitz Rodas
Jefferson Lab

Astrid Hiller Blin
EK University of Tübingen

César Fernández Ramírez
UNED/ICN-UNAM

Daniel Winney
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Emilie Passemar
Indiana University

Gloria Montaña
Jefferson Lab

Łukasz Bibrzycki
AGH University of Krakow

Miguel Albaladejo
IFIC-CSIC Valencia

Mikhail Mikhasenko
LMU Munich

Robert Perry
University of Barcelon

Sergi Gonzàlez-Solís

Vanamali Shastry

Viktor Mokeev

Vincent Mathieu
University of Barc

Wyatt Smith
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Affiliated Members

Andrew Jackura
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ICN-UNAM

Kevin Quirion
Indiana University

Michael Döring
George Washington University

Nadine Hammoud
INP Krakow

Ron Workman
George Washington University

Sebastian Marek Dawid
University of Washington

Former Members

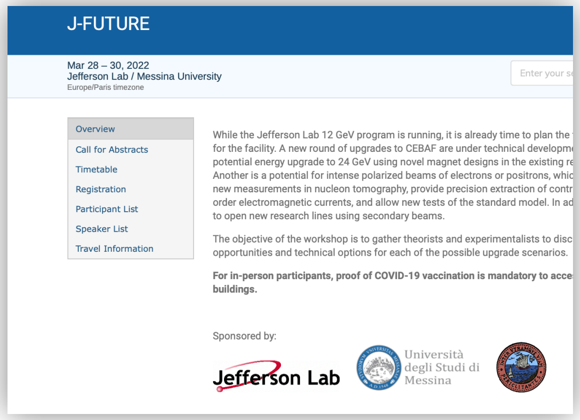
- Diane Schott
- Ina Lorenz
- Jannes Nys
- Ling-Yun Dai
- Meng Shi
- Nathan Sherrill
- Peng Guo
- Tim Londergan
- Vladyslav Pauk

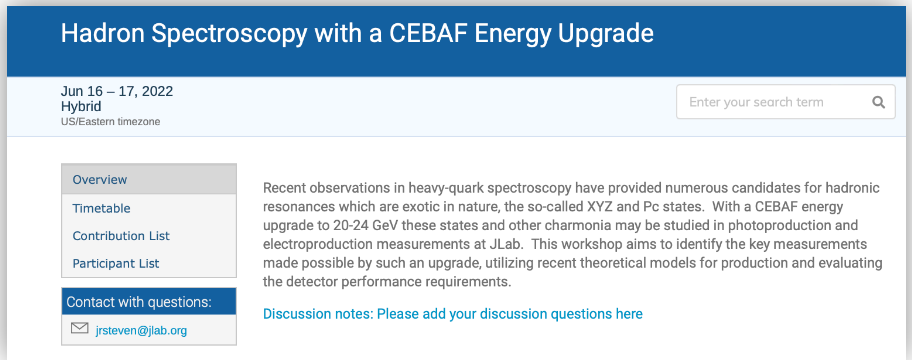
- Over time ~40 researchers have been associated with JPAC.
- Majority of former postdocs have long-term or permanent positions.
- Tuesday's JPAC meetings have run continuously for the past 10 years (record over 8h)

Brief history continues

- (co-)organized over 30 international conferences and workshops,
- including our “own” series: 4 editions of Future Directions in Spectroscopy Analysis (FDSA),
- Two Summer Schools (2015,2017), INT Program (2020)
- Graduate course on reaction

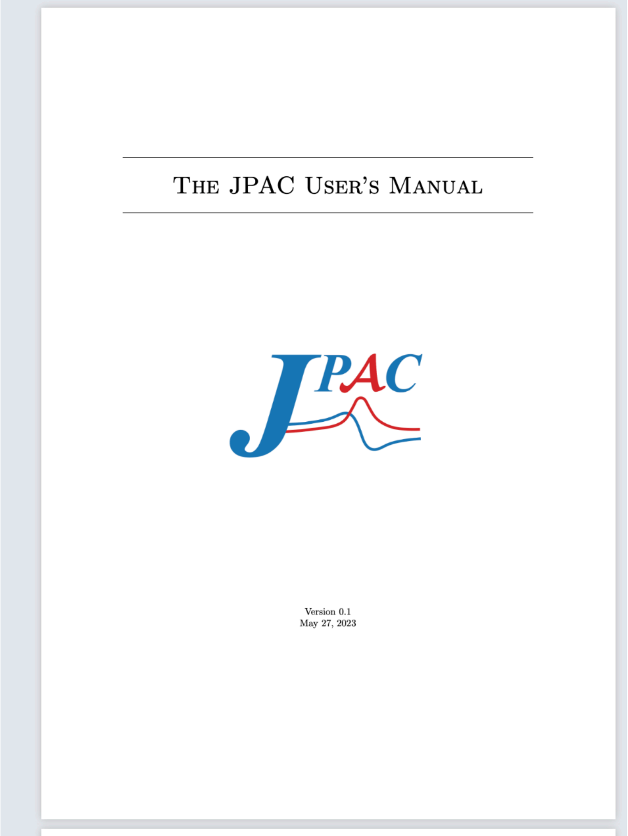
- JPAC served as a liaison between many theoretical and experimental analysis efforts BaBar,BESIII,COMPASS,EIC, LHCb,JLab





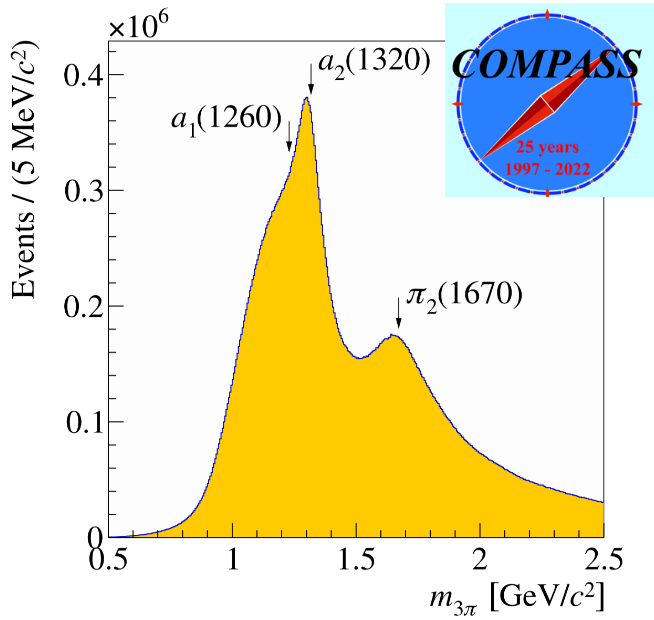
What has made JPAC successful

- JPAC is comprised of people from different backgrounds
- JPAC's priority is to provide an intellectually stimulating environment, create future carrier opportunities for it members
- We adopted a horizontal management structure, with decisions made by consensus shared responsibilities and benefits (e.g. publication policy)

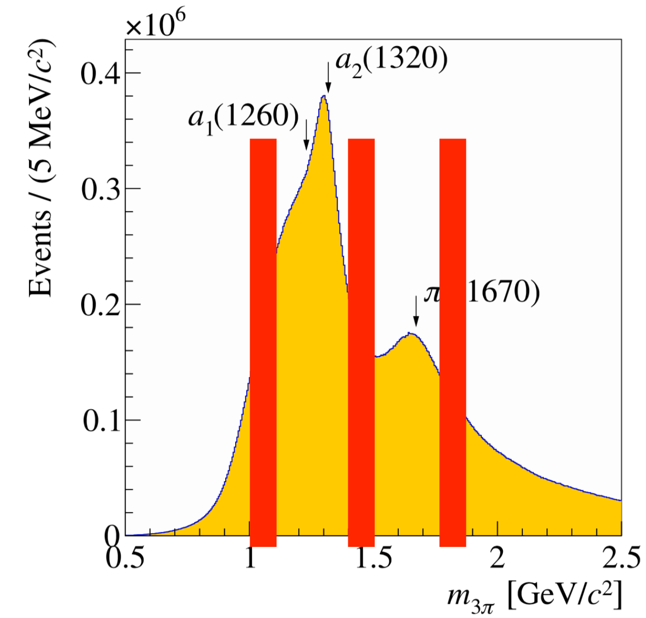

THE JPAC USER'S MANUAL

Version 0.1
May 27, 2023

Amplitude analysis

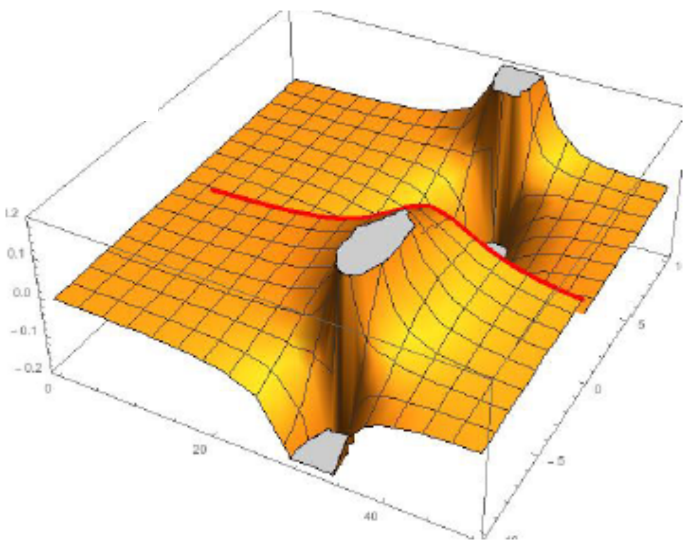


Nature: real axes



QCD

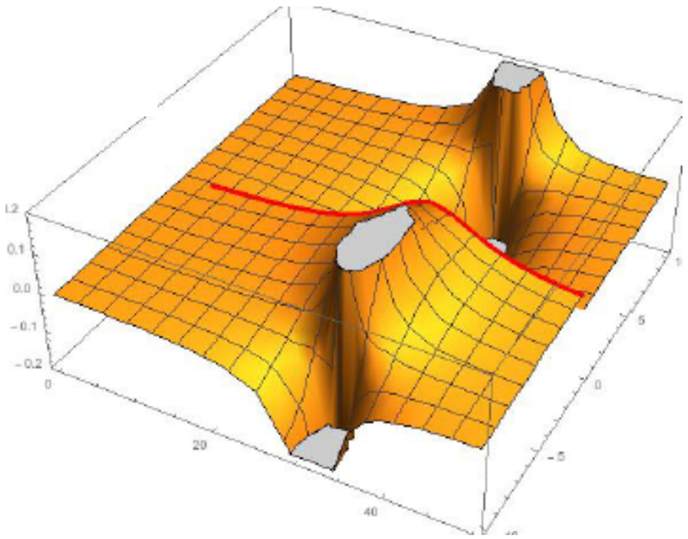
For new results see : W.Smith
"Mathematical ambiguities in $\eta\pi$ photoproduction" Session : Analysis Tools on Thursday at 14:35 PM



JPAC's philosophy: Let the data tell us about the underlying phenomena (not the other way around)

Physical interpretation

Amplitude analysis



1. Amplitudes are analytical functions of $s_1, \cdots t_1, \cdots$

2. Partial wave amplitudes are analytical functions angular momentum

$$f_l(s) = f(l, s)$$

3. Physical sheet singularities are given by unitarity

4. Unphysical sheet singularities need to be parametrized in order to test microscopic models

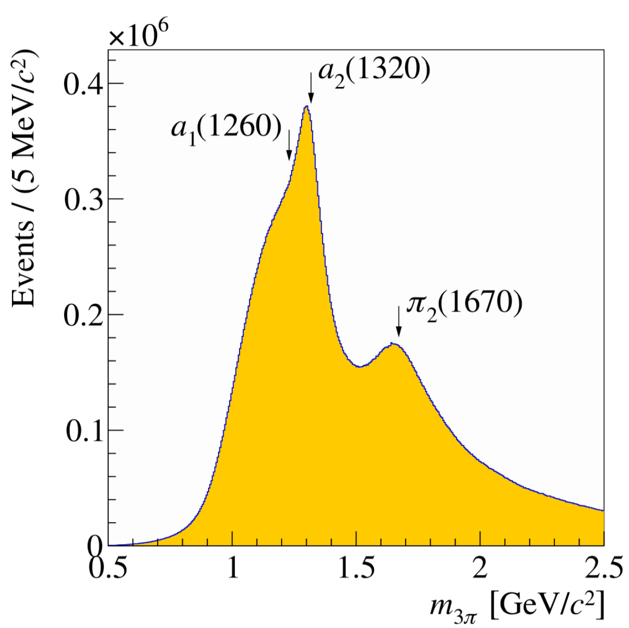
For new results see : M.Albaladejo " Khuri-Treiman analysis of the $J/\psi \to \pi^+\pi^-\pi^0$ reaction" Session: Light Meson Spectroscopy. Friday at 9:25, A.Rodas "Dispersive determination of the σ resonance from lattice QCD, Monday 16:25

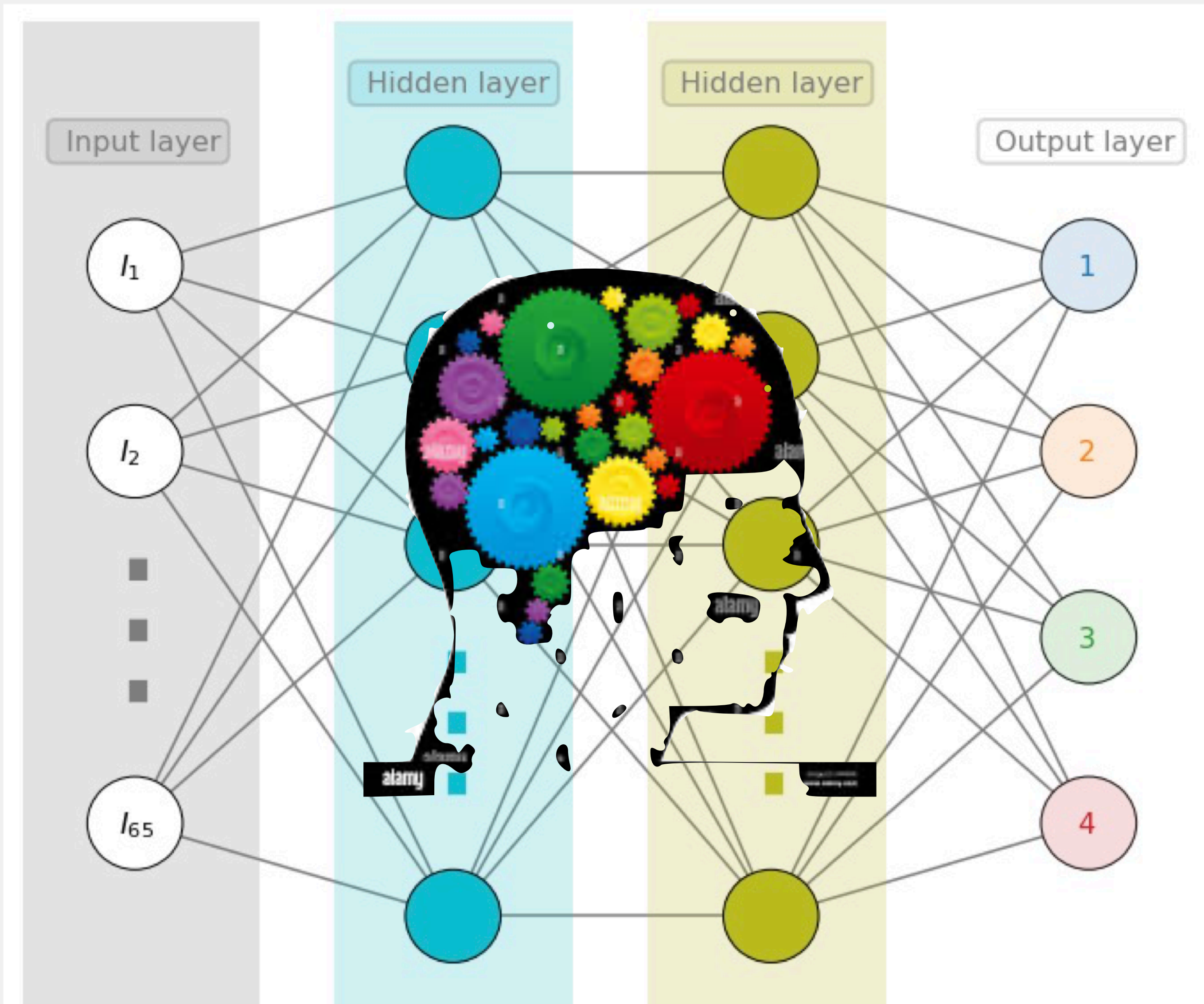
Holy Grail: AI as a tool for physics discovery

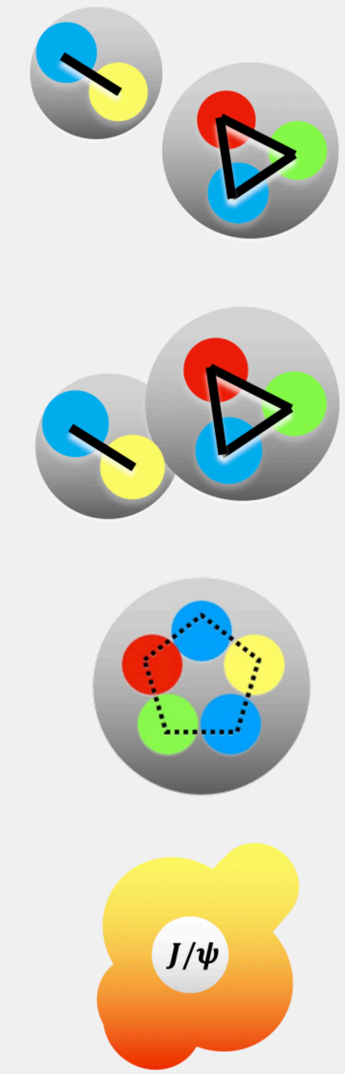
$$S = T\left[\exp\left(-i\int_{-\infty}^{\infty} dt H'_I(t)\right)\right]$$

Teach

Apply to data



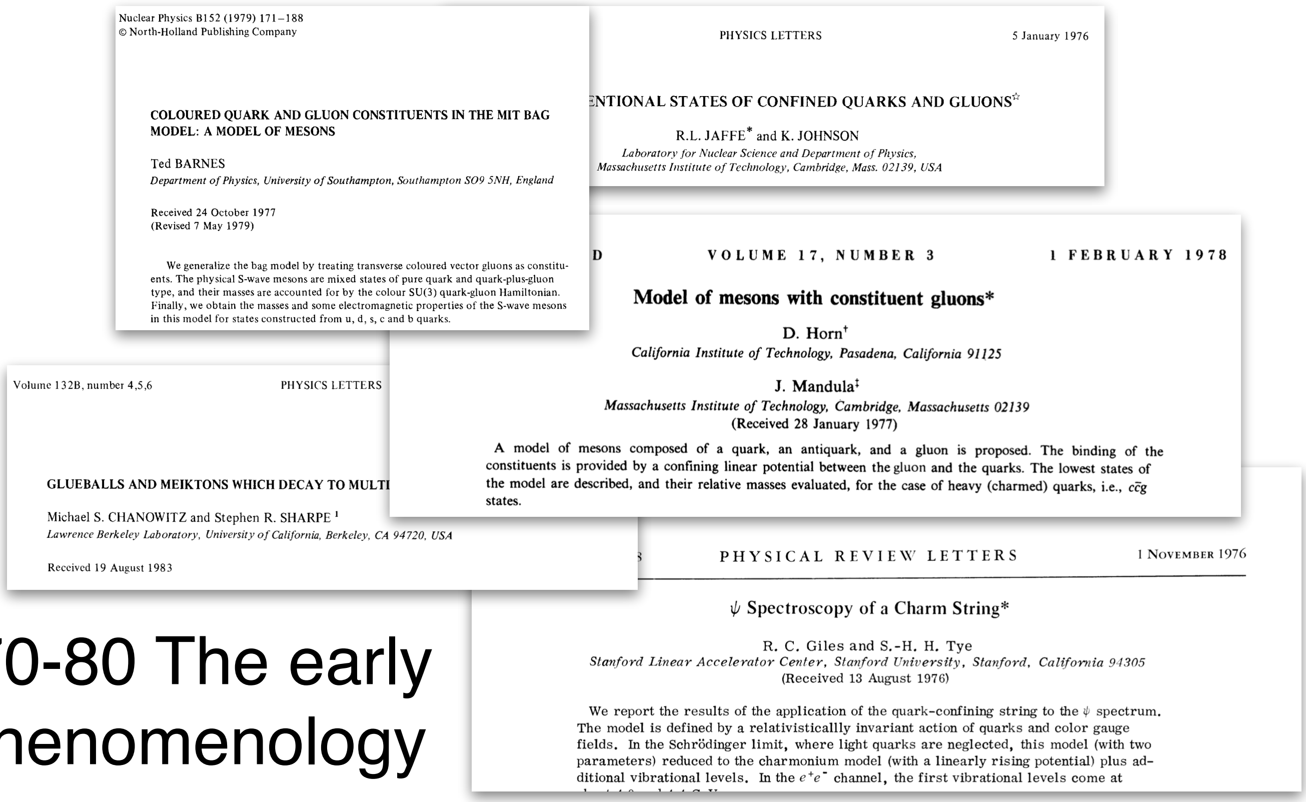




Tell the story

C.Fernandez-Ramirez “Pole extraction and nature of the f0(980)” Session: Light Meson Spectroscopy. Wednesday at 17:50

Brief history of exotics (hybrids)


Nuclear Physics B152 (1979) 171–188
© North-Holland Publishing Company

COLOURED QUARK AND GLUON CONSTITUENTS IN THE MIT BAG MODEL: A MODEL OF MESONS

Ted BARNES
Department of Physics, University of Southampton, Southampton SO9 5NH, England

Received 24 October 1977
(Revised 7 May 1979)

We generalize the bag model by treating transverse coloured vector gluons as constituents. The physical S-wave mesons are mixed states of pure quark and quark-plus-gluon type, and their masses are accounted for by the colour SU(3) quark-gluon Hamiltonian. Finally, we obtain the masses and some electromagnetic properties of the S-wave mesons in this model for states constructed from u, d, s, c and b quarks.

PHYSICS LETTERS 5 January 1976

...ENTIONAL STATES OF CONFINED QUARKS AND GLUONS

R.L. JAFFE* and K. JOHNSON
Laboratory for Nuclear Science and Department of Physics, Massachusetts Institute of Technology, Cambridge, Mass. 02139, USA

VOLUME 17, NUMBER 3 1 FEBRUARY 1978

Model of mesons with constituent gluons*

D. Horn†
California Institute of Technology, Pasadena, California 91125

J. Mandula‡
Massachusetts Institute of Technology, Cambridge, Massachusetts 02139
(Received 28 January 1977)

A model of mesons composed of a quark, an antiquark, and a gluon is proposed. The binding of the constituents is provided by a confining linear potential between the gluon and the quarks. The lowest states of the model are described, and their relative masses evaluated, for the case of heavy (charmed) quarks, i.e., $c\bar{c}g$ states.

Volume 132B, number 4,5,6 PHYSICS LETTERS

GLUEBALLS AND MEIKTONS WHICH DECAY TO MULTI...

Michael S. CHANOWITZ and Stephen R. SHARPE [1]
Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94720, USA

Received 19 August 1983

PHYSICAL REVIEW LETTERS 1 November 1976

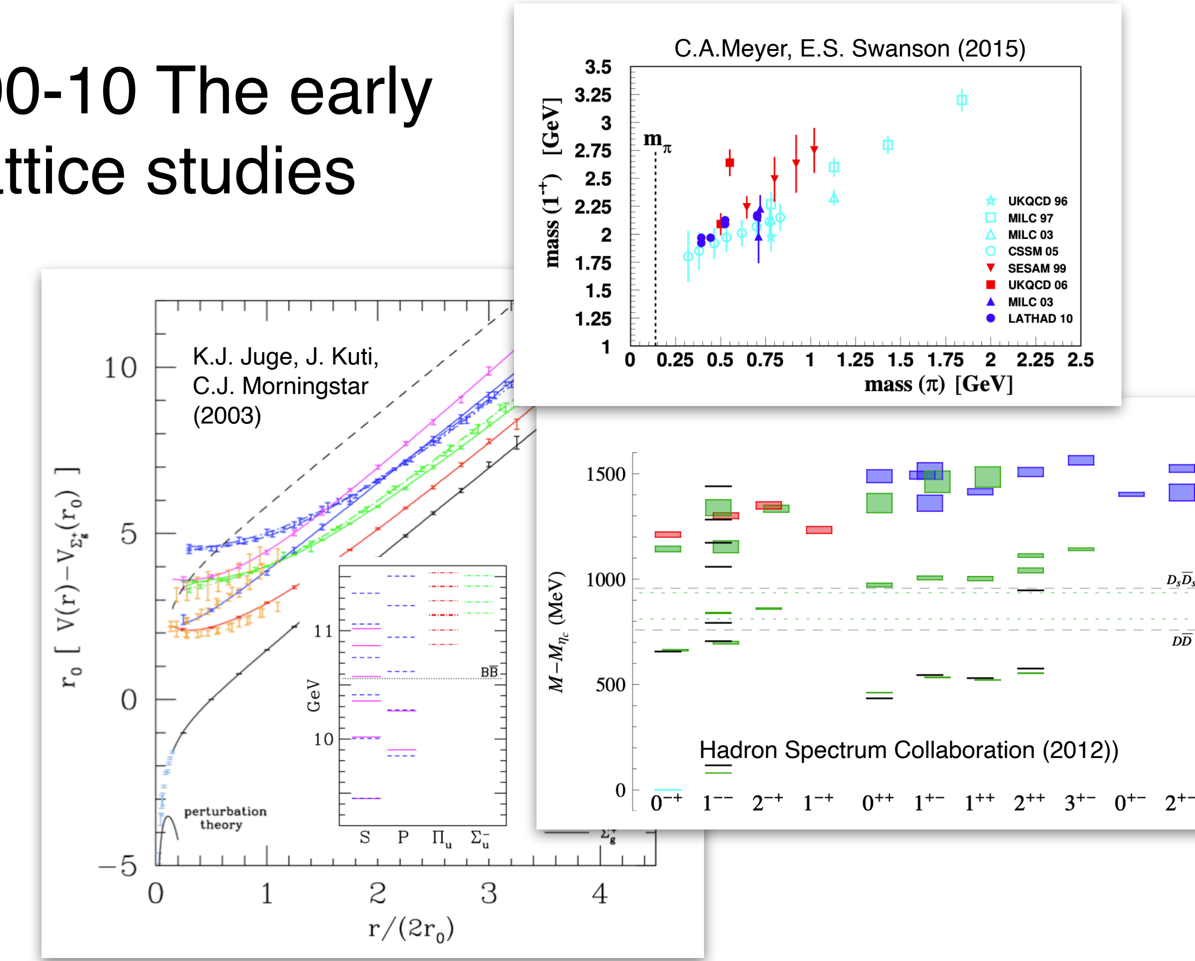
ψ Spectroscopy of a Charm String*

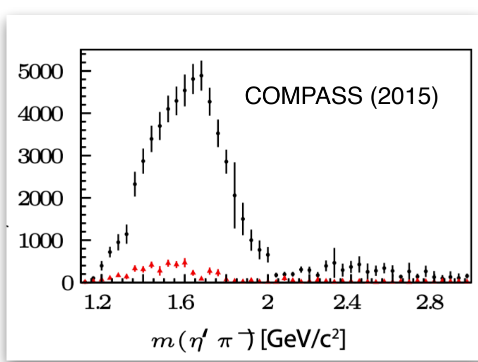
R. C. Giles and S.-H. H. Tye
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305
(Received 13 August 1976)

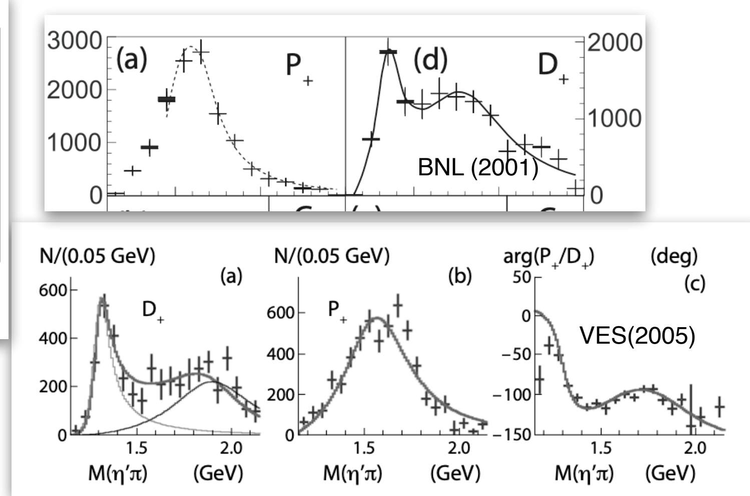
We report the results of the application of the quark-confining string to the ψ spectrum. The model is defined by a relativistically invariant action of quarks and color gauge fields. In the Schrödinger limit, where light quarks are neglected, this model (with two parameters) reduced to the charmonium model (with a linearly rising potential) plus additional vibrational levels. In the e^+e^- channel, the first vibrational levels come at

- '70-80 The early phenomenology

- '00-10 The early lattice studies

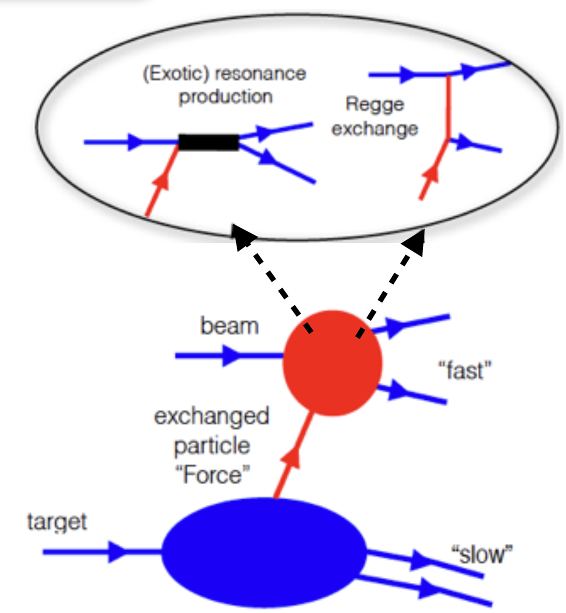






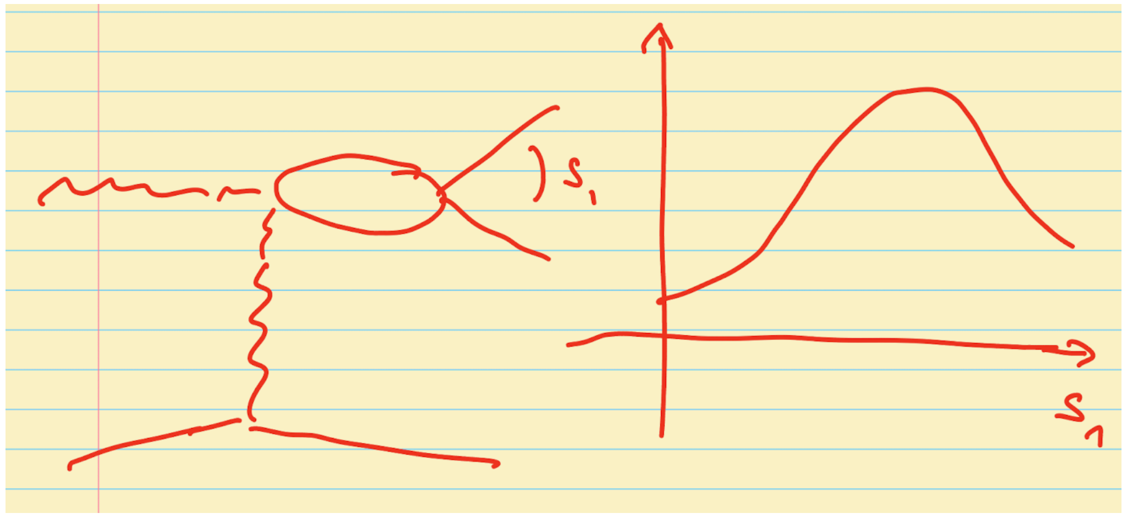
- '00-10 The early data

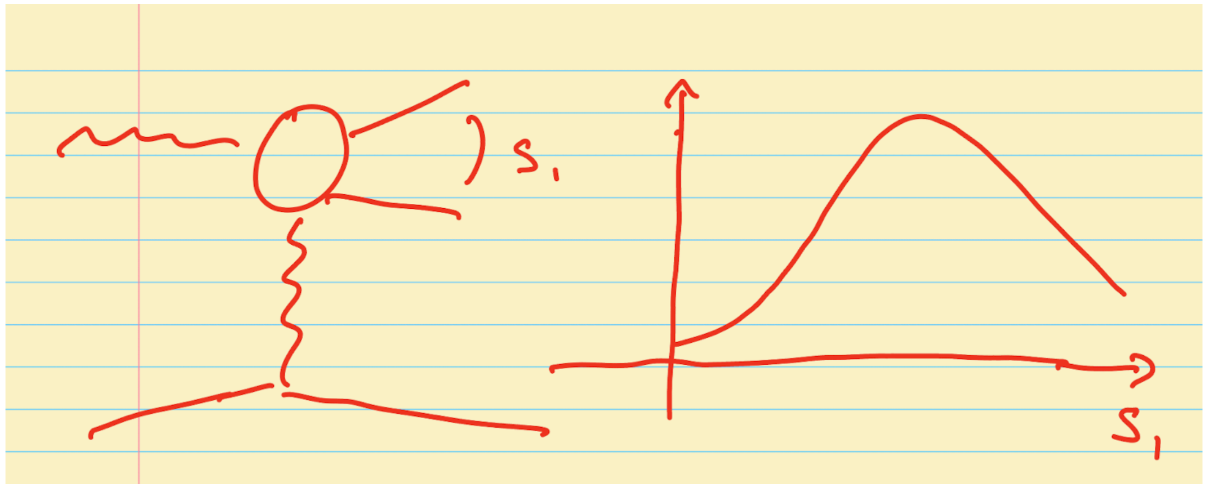
- New perspectives : GlueX,CLAS12, COMPAS, JPAC…



To Resonate or not to Resonate

- The $a_1(1260)$ was for some time confused with the pion exchange

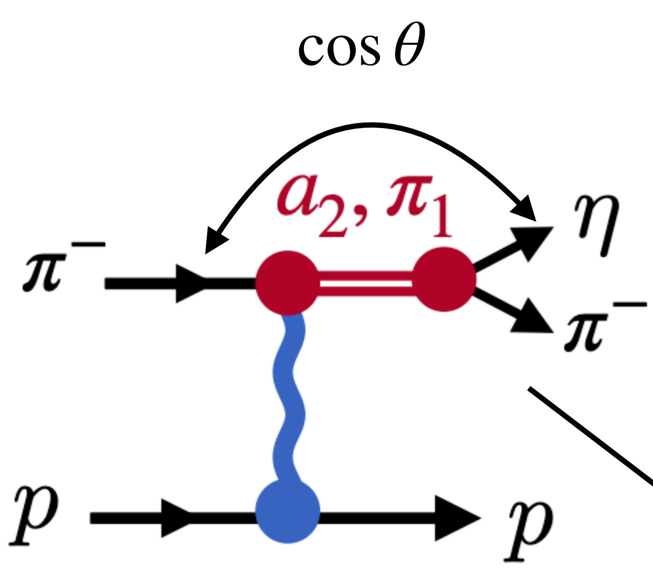




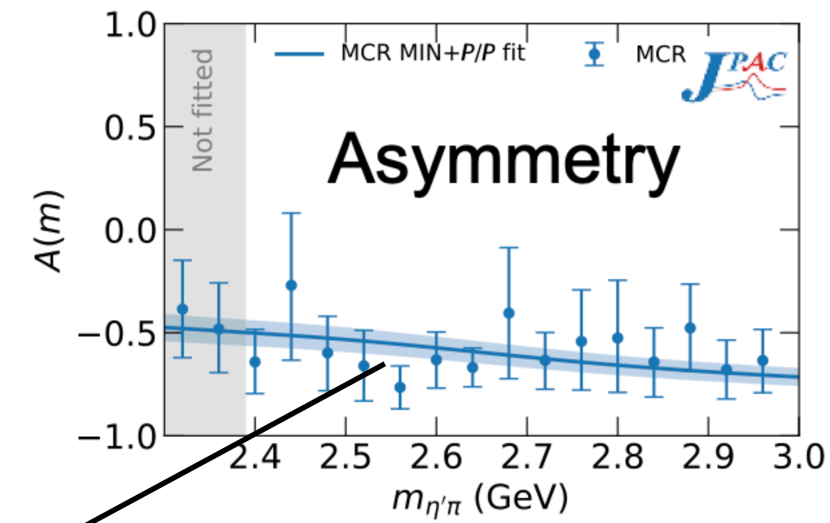
- It is very important to understand production mechanisms : explore analyticity in various kinematical variables

R.Perry: Two pion photo production in the Regge region" Session: Light hadron spectroscopy, Wet 14:30

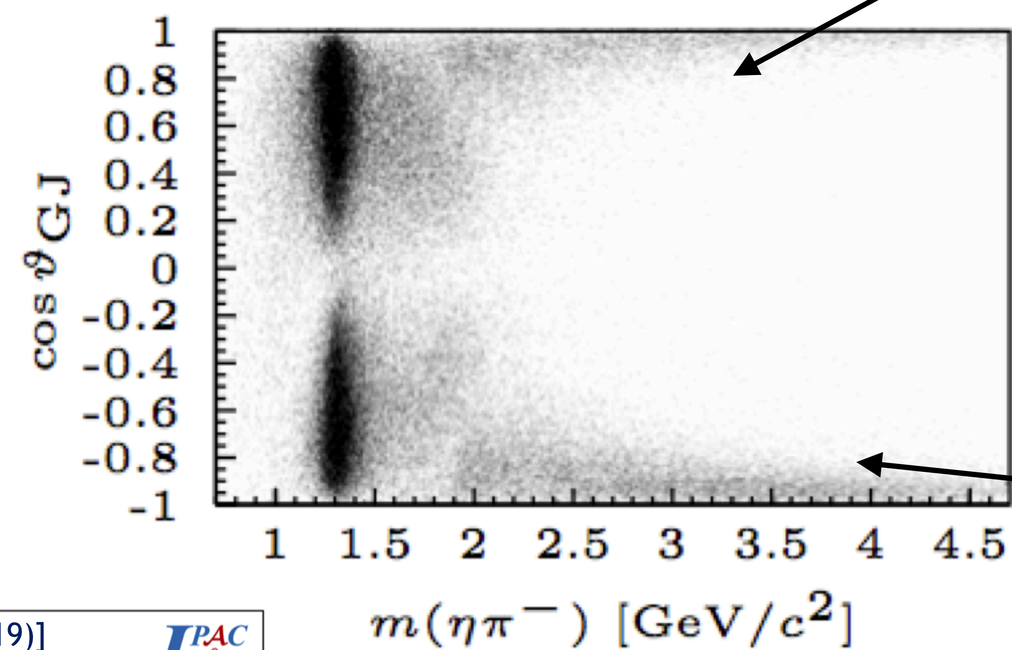
To Resonance or not to Resonate

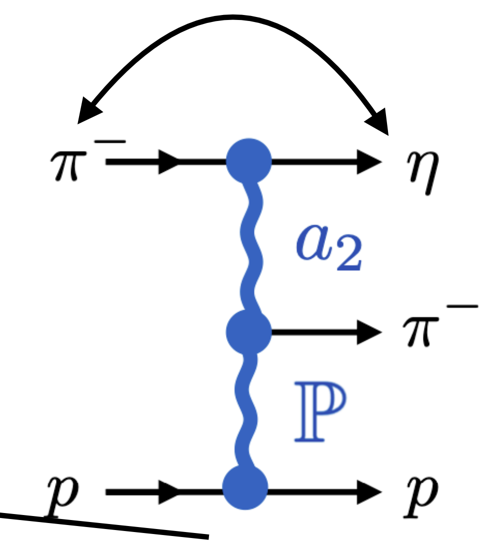


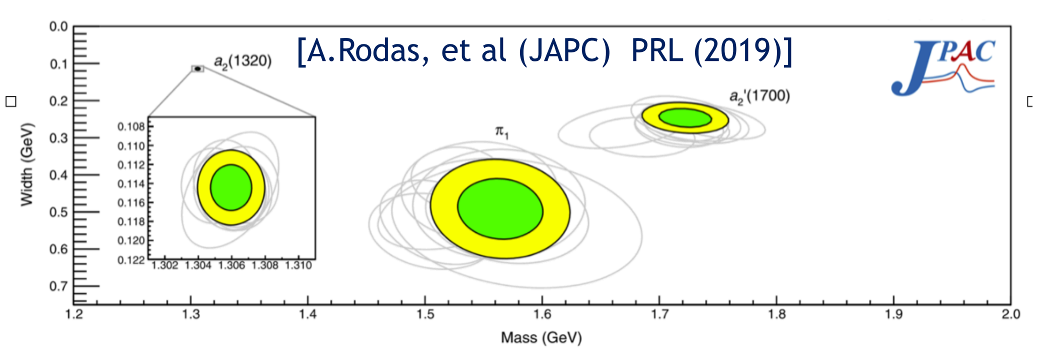
Bibrzycki et al (JPAC) EPJC81 (2021) 915



- Amplitude is analytical in $\cos(\theta)$ when $s_{\eta\pi}$ near a resonance

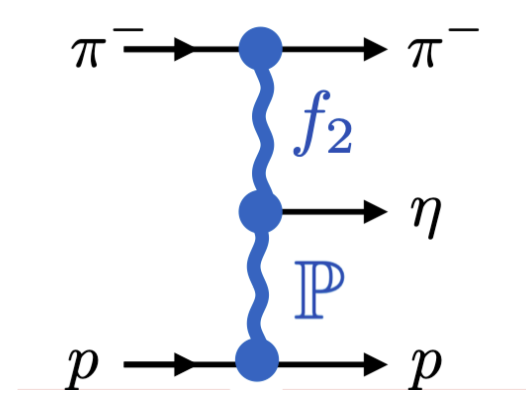






Poles	Mass (MeV)	Width (MeV)
$a_2(1320)$	$1306.0 \pm 0.8 \pm 1.3$	$114.4 \pm 1.6 \pm 0.0$
$a_2'(1700)$	$1722 \pm 15 \pm 67$	$247 \pm 17 \pm 63$
π_1	$1564 \pm 24 \pm 86$	$492 \pm 54 \pm 102$

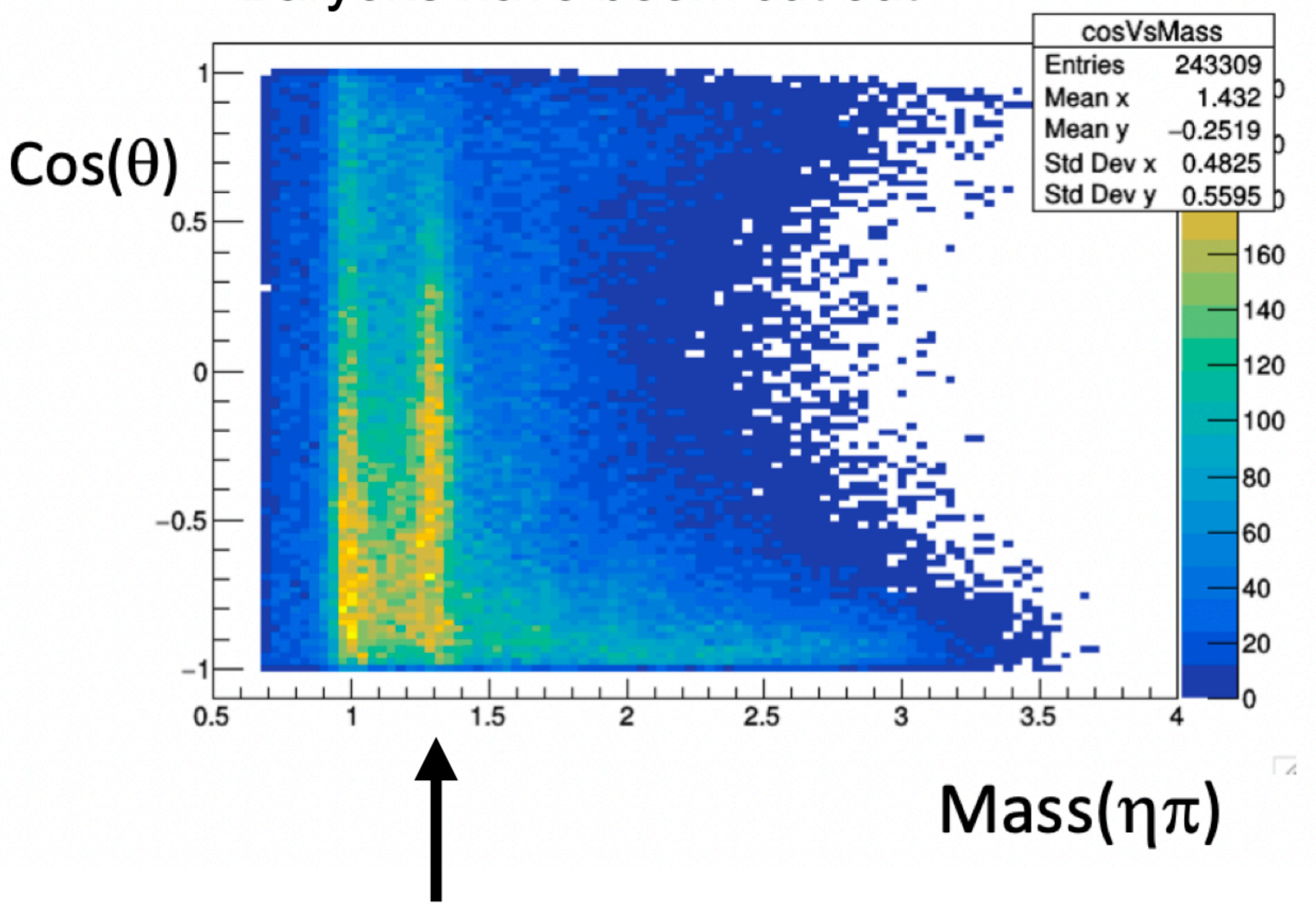
- Singularities of $\cos(\theta)$ exposed for large $s_{\eta\pi}$



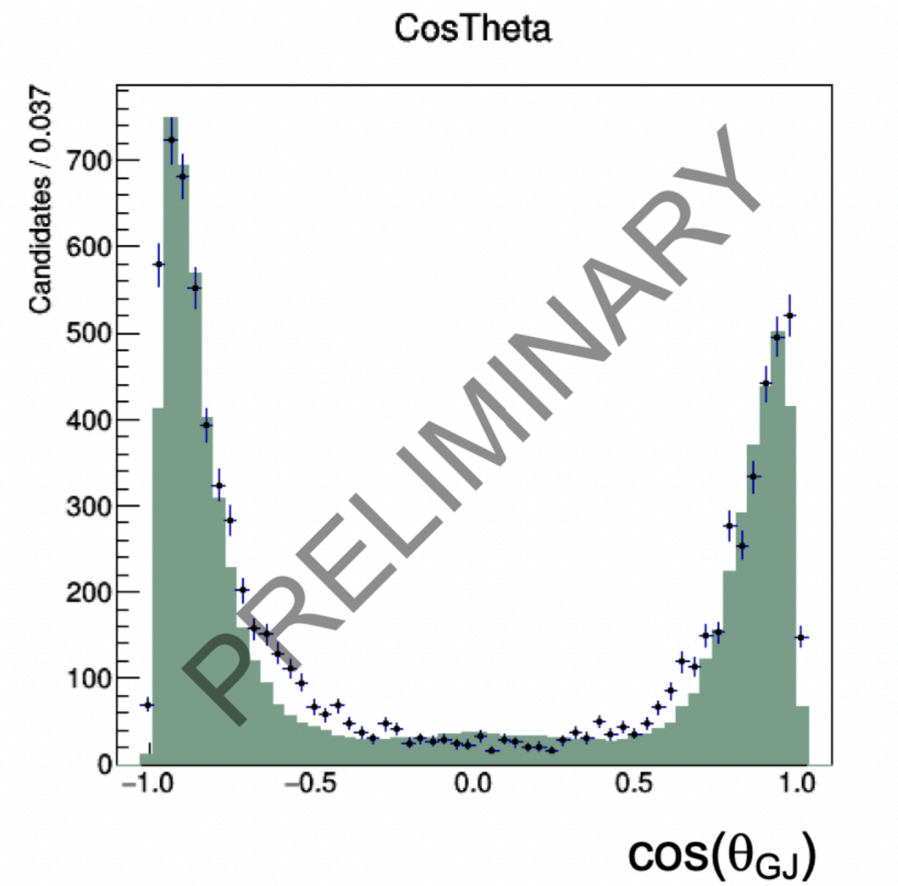
$\eta\pi^0$ Photoproduction@GlueX

In collaboration with R. Barsotti

Baryons have been 'cut out'



$a_2(1320)$



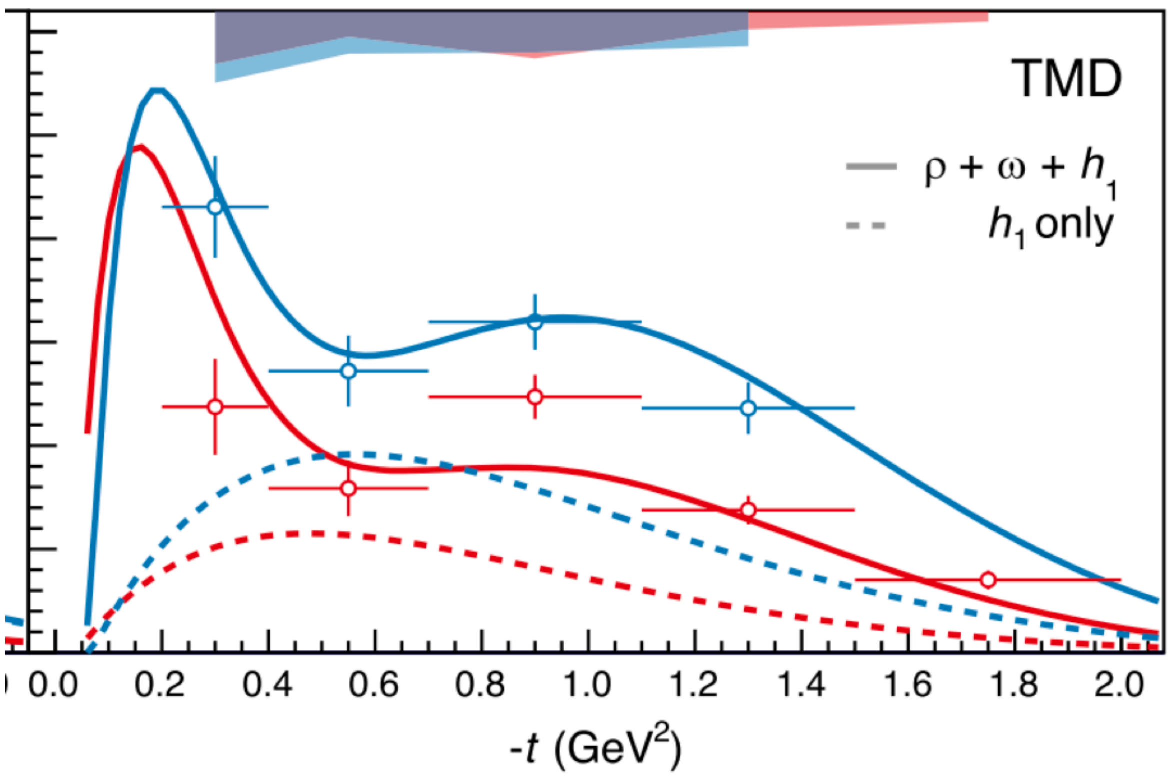
Double regge with Uniform background

Vincent Mathieu

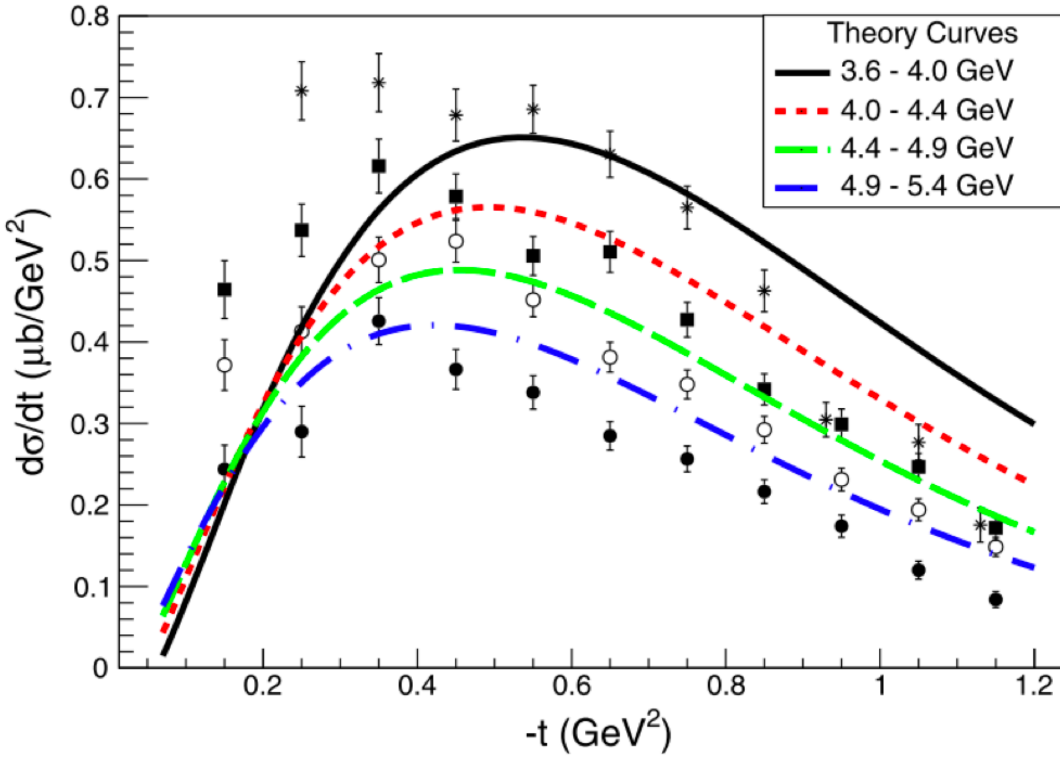
Tensor Meson Photoproduction @CLAS

VM et al (JPAC) PRD102 (2020)

CLAS PRC 102 (2020)

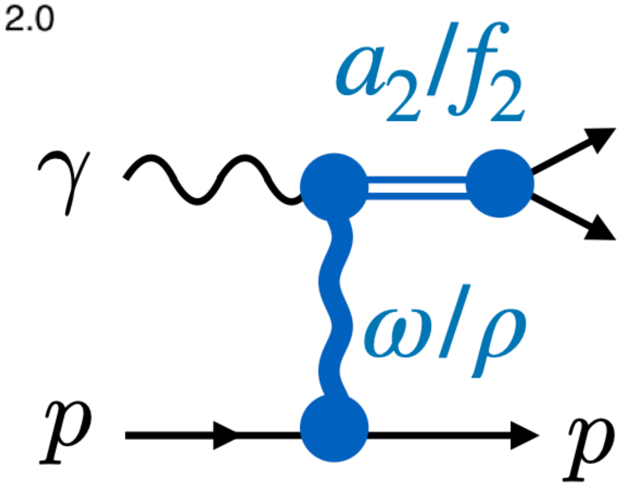


CLAS PRL126 (2021)



$$\gamma p \to a_2(1320)p :$$

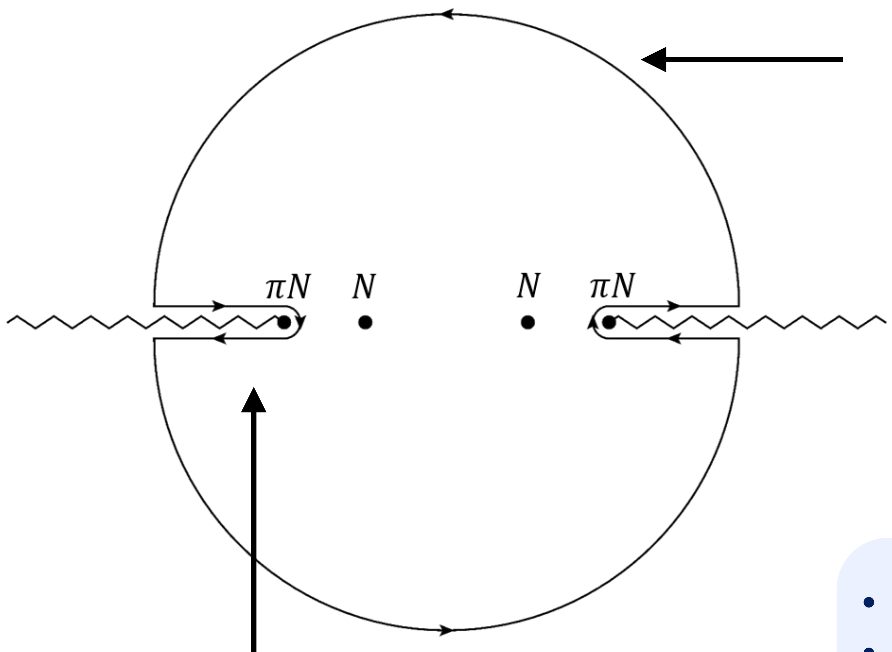
$$\omega + \frac{1}{3}\rho$$

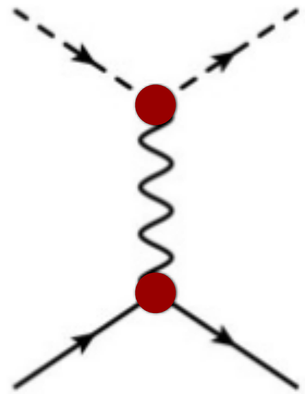


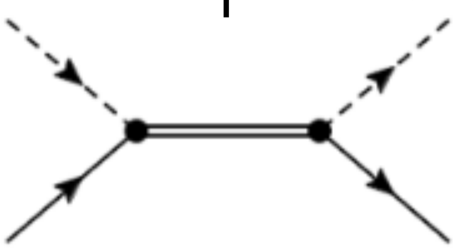
$$\gamma p \to f_2(1270)p :$$

$$\rho + \frac{1}{3}\omega$$

Finite Energy Sum Rules





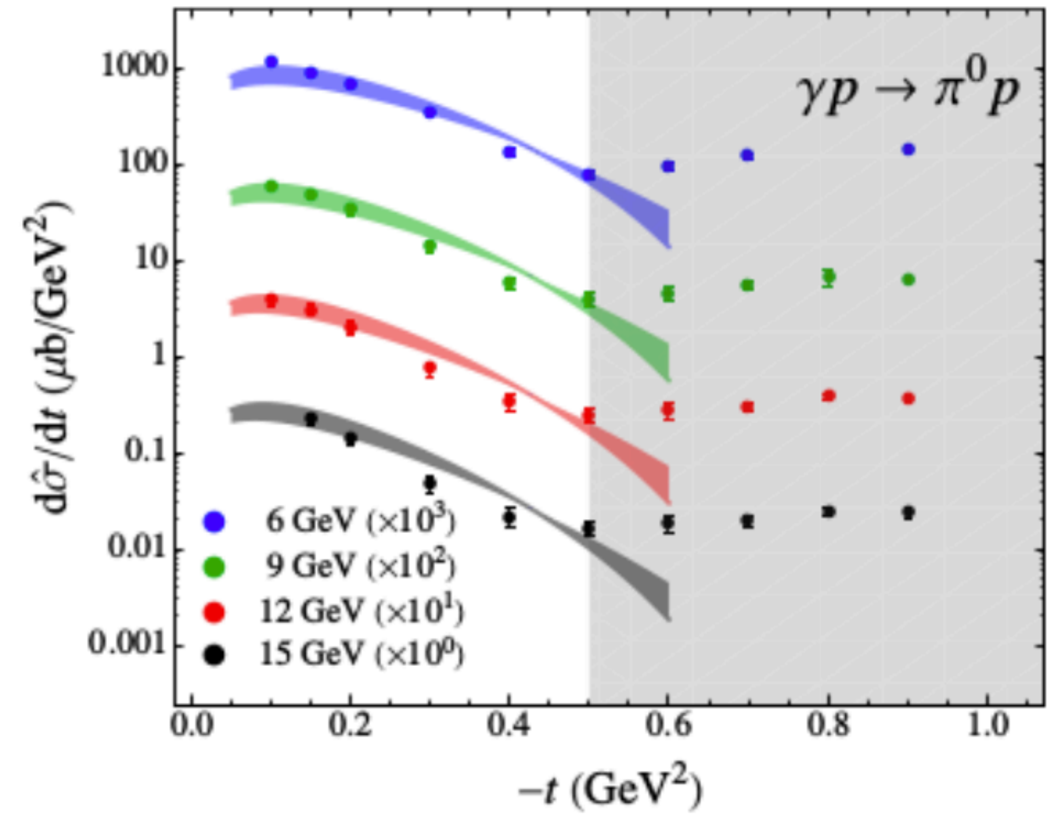


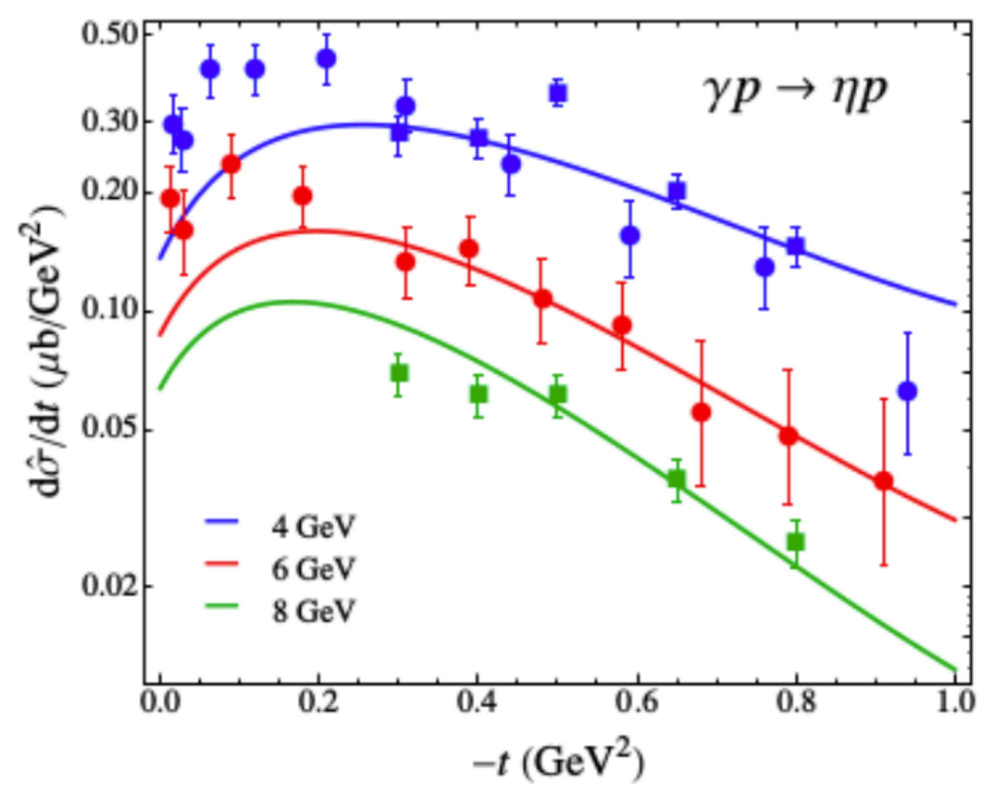
- No kinematic singularities
- No kinematic zeros
- Discontinuities:
  - Unitarity cut
  - Nucleon pole

$$A_{\lambda';\lambda\lambda_\gamma}(s,t) = \overline{u}_{\lambda'}(p')\left(\sum_{k=1}^{4} A_k(s,t) M_k\right) u_\lambda(p)$$

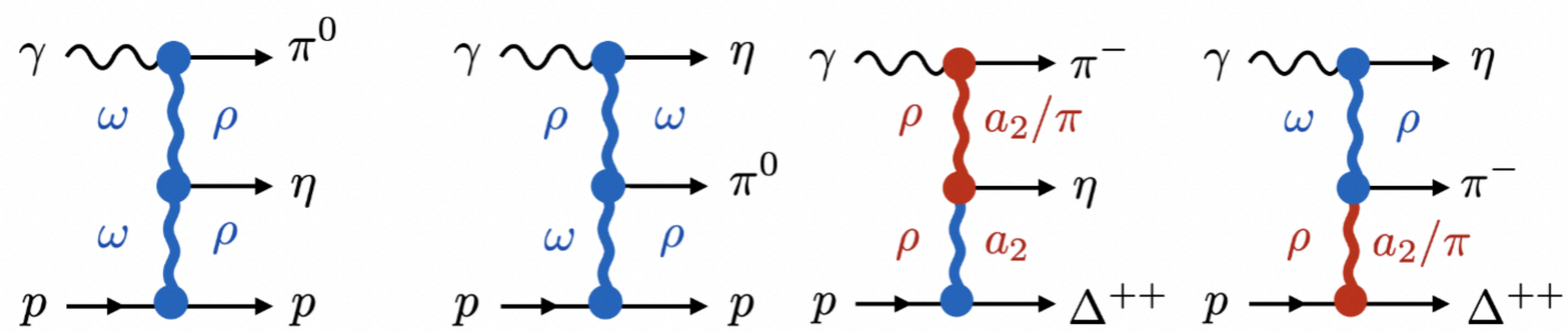
$$\int_0^\Lambda \mathrm{Im}\ A_i(\nu,t)\nu^k d\nu = \beta_i(t)\frac{\Lambda^{\alpha(t)+k}}{\alpha(t)+k}$$

$$\boxed{\beta_i(t) = \frac{\alpha(t)+k}{\Lambda^{\alpha(t)+k}}\int_0^\Lambda \mathrm{Im}\ A_i(\nu,t)\nu^k d\nu}$$





Dispersion relation (FESR's) for 2-to-3



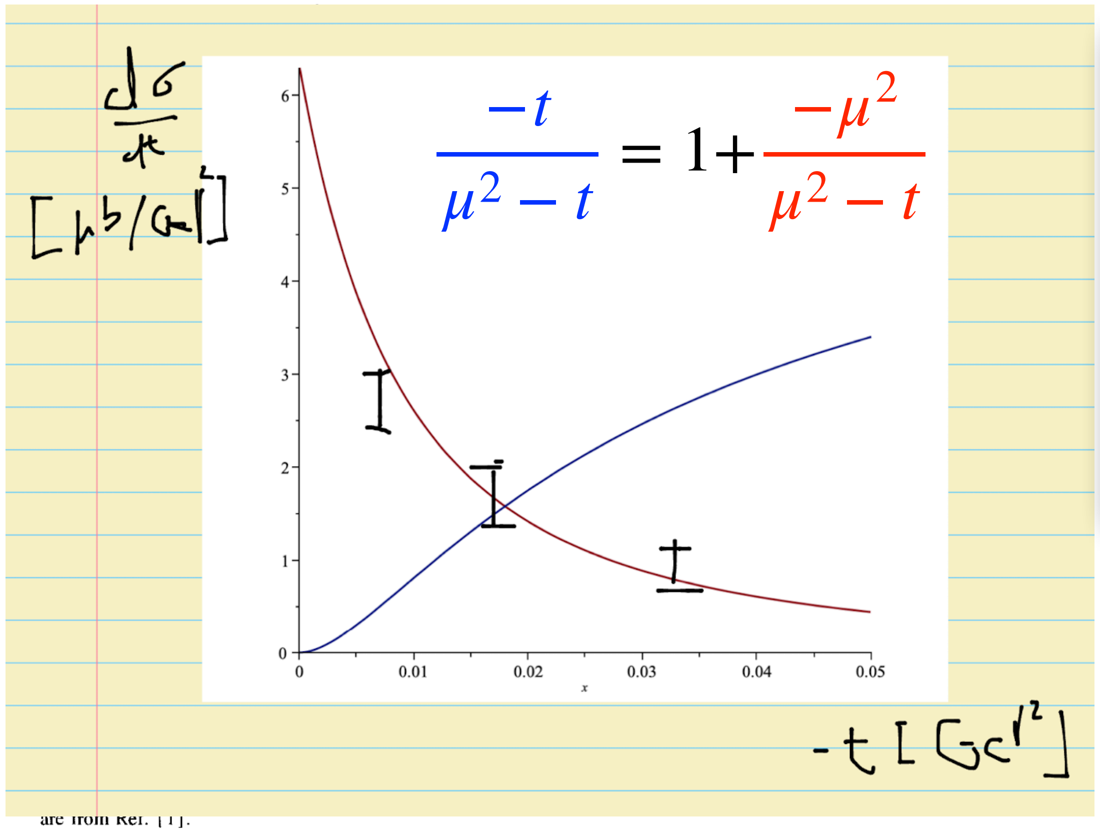
- Dispersion relations (FESR's) for 2-to-3 more powerful then in 2-to-2 processes (various types) !

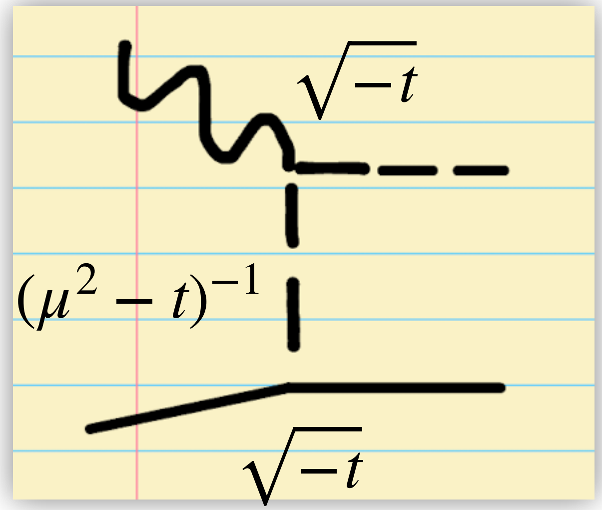
- The middle vertex can be measured: what information is there in helicity dependence of the "middle" vertex)

- Sparse applications

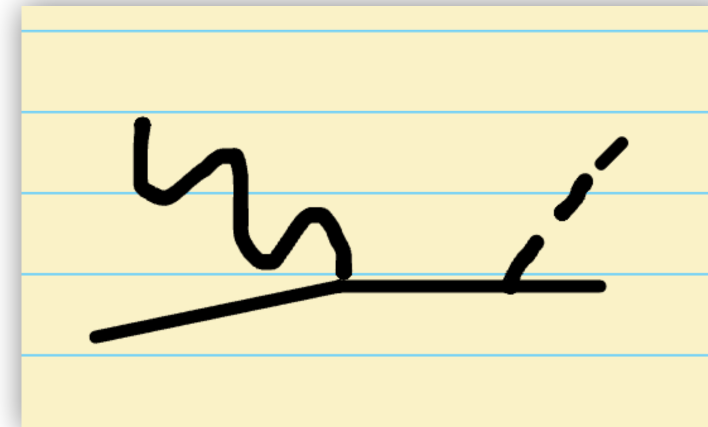
DeTarr et al. (1974), Hoyer (1973) , Schimada et al (1978) , Bibrzycki at al (JPAC) (2021)

Pion exchange





Vs



- Photproduction would be the “cleanest” probe of OPE except : how much “pion is in pion exchange” is frame dependent

- Other questions: what is responsible for raising $d\sigma/dt$? (nucleon magnetic term or absorption, e.g. $pn \to np$)

- How does OPE at high energy compares to OPE at low energies or OPE between heavy quarkonia?

ongoing GLueX analyses

$$\gamma p \to \pi^+ n$$
$$\to \pi^- \Delta^{++}$$
$$\to b_1(n, \Delta)$$
$$\to a_2(N, \Delta)$$

Spectroscopy at the future facilities

XYZP **spectroscopy at a charm photoproduction factory**

M. Albaladejo,[1] M. Battaglieri,[2,3] A. Esposito,[4] C. Fernández-Ramírez,[5]
A. N. Hiller Blin,[1] V. Mathieu,[6] W. Melnitchouk,[1] M. Mikhasenko,[7] V. I. Mokeev,[2]
A. Pilloni,[3,8,*] A. D. Polosa,[9] J.-W. Qiu,[1] A. P. Szczepaniak,[1,10,11] and D. Winney[10,11]

LoI RF7_RF0_120

arXiv:2203.08290

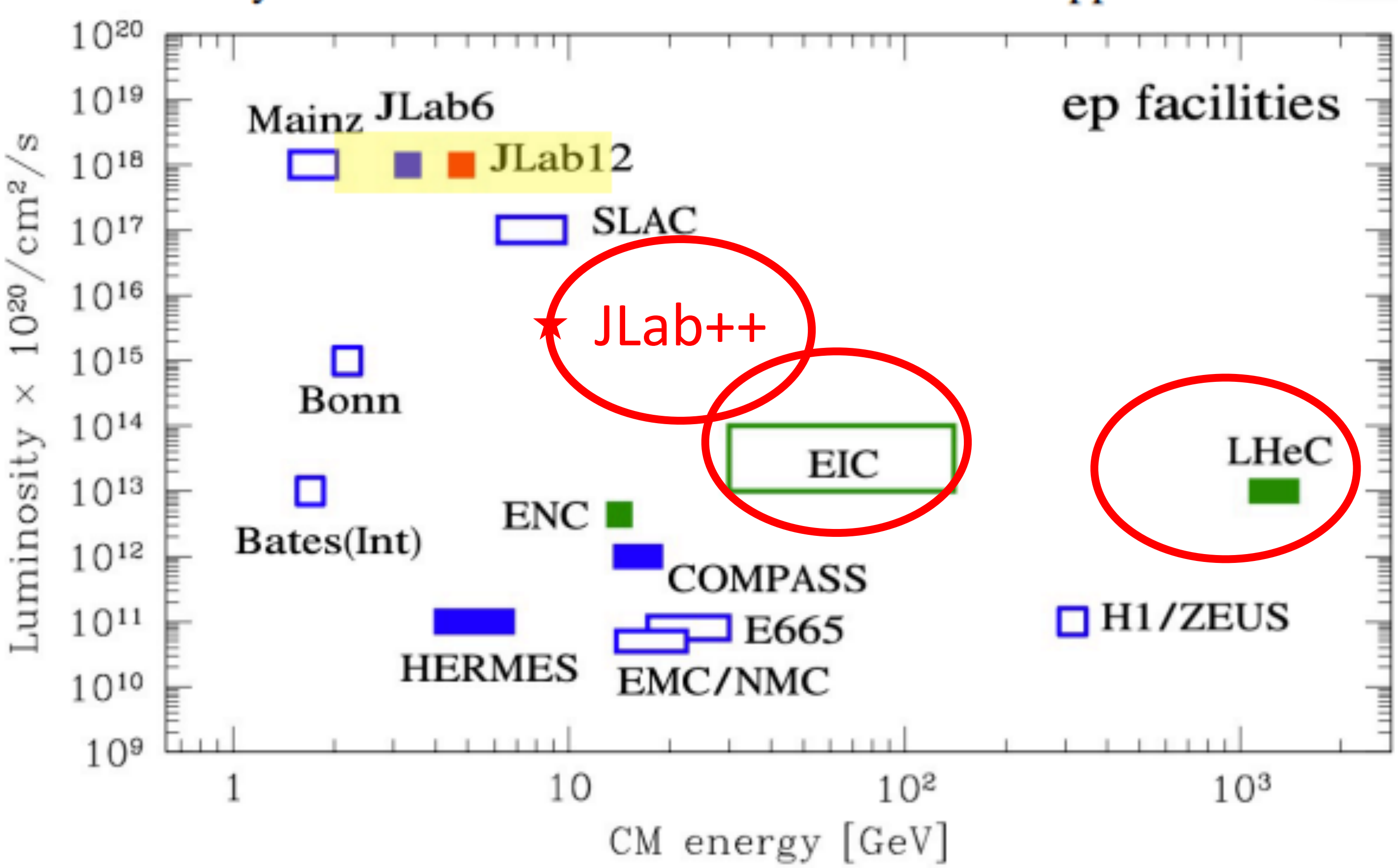
Submitted to the Proceedings of the US Community Study
on the Future of Particle Physics (Snowmass 2021)

Hadron Spectroscopy in Photoproduction

Miguel Albaladejo[1], Łukasz Bibrzycki[2], Sean Dobbs[3], César Fernández-Ramírez[4,5],
Astrid N. Hiller Blin[6], Vincent Mathieu[7,8], Alessandro Pilloni[9,10], Justin Stevens[11],
Adam P. Szczepaniak[12,13,14], and Daniel Winney[13,14,15,16]

arXiv:2112.00060

Physics with CEBAF at 12 GeV and Future Opportunities



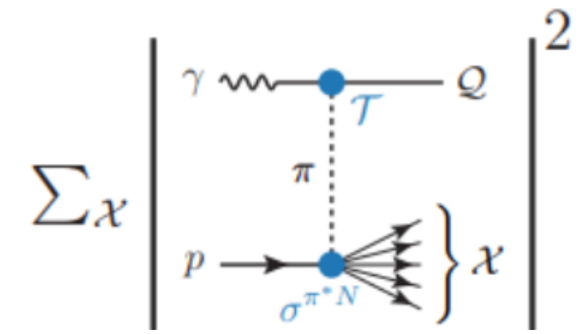
Ent[2],
Qiu[2,8],

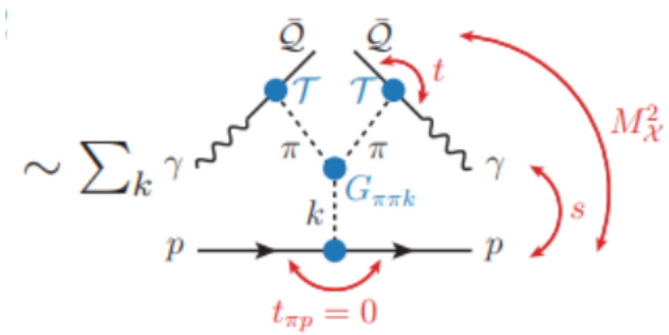
EIC/JLab++ explore the complementarity of diffraction, peripheral and/or direct production

Spectroscopy at the future facilities

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

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





	17 GeV		24 GeV	
	produced	detected	produced	detected
$Z_c(3900)^+$	2.2 k	371	4.2 k	588
$X(3872)$	1.1 k	32	4.2 k	63

TABLE I. Estimates of yields for day of data taking at CLAS24 assuming a zero-angle electron detector

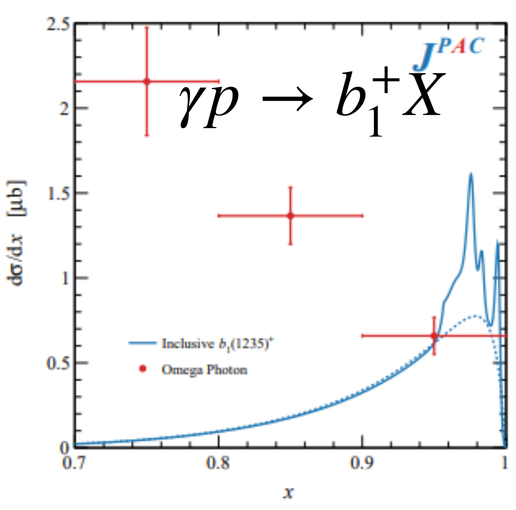
See D.Glazier "Prospects for exotic mesons" at the EIC" Tuesday 17:20

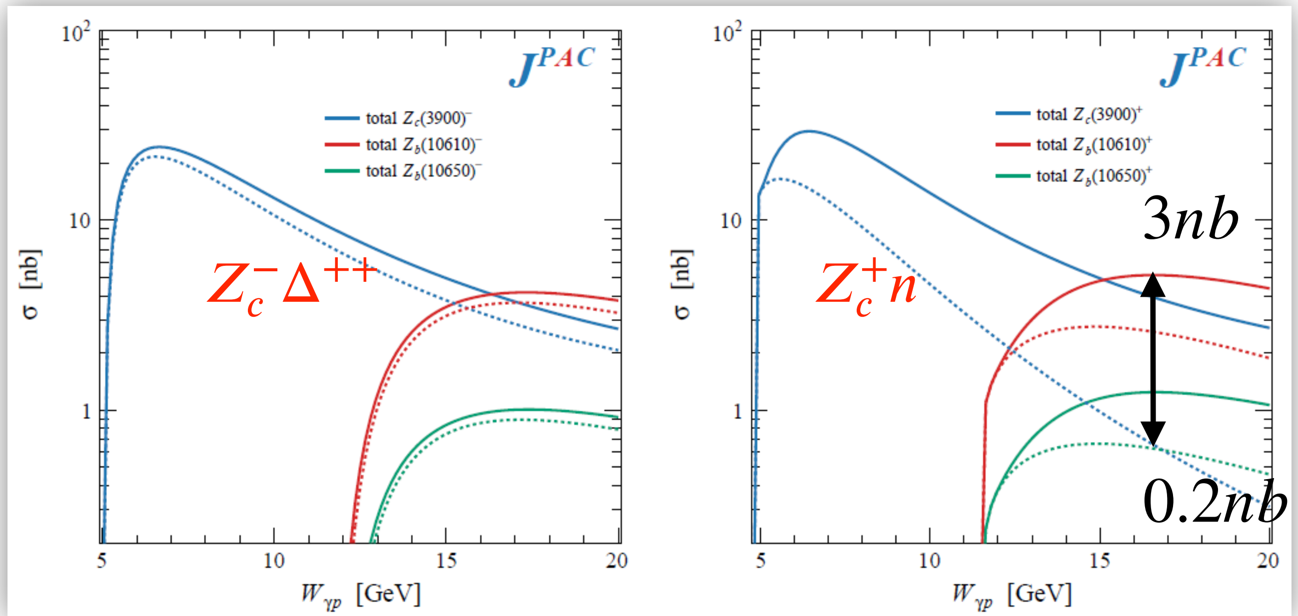
TABLE II. Summary of results for production of some states of interest at the EIC electron and proton beam momentum $5 \times 100 (GeV/c)$ (for electron x proton). Columns show : the meson name; our estimate of the total cross section; production rate per day, assuming a luminosity of 6.1×10^{33} cm^{-2}s^{-1};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

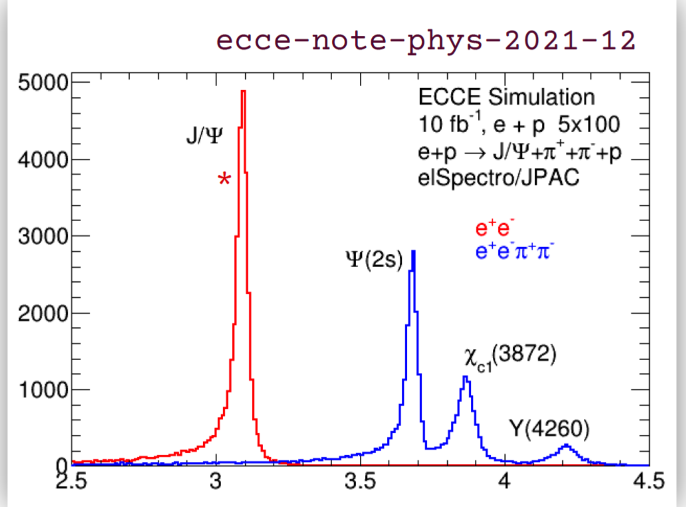
Meson	Cross Section (nb)	Production rate (per day)	Decay Branch	Branch Ratio (%)	Events (per day)
$\chi_{c1}(3872)$	2.3	2.0 M	$J/\Psi\, \pi^+\pi^-$	5	6.1 k
$Y(4260)$	2.3	2.0 M	$J/\Psi\, \pi^+\pi^-$	1	1.2 k
$Z_c(3900)$	0.3	0.26 M	$J/\Psi\, \pi^+$	10	1.6 k
$X(6900)$	0.015	0.013 M	$J/\Psi\, J/\Psi$	100	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

- 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



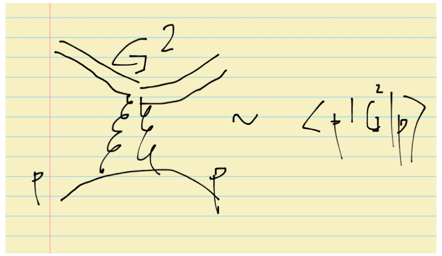




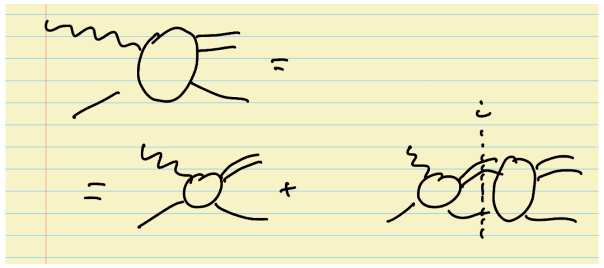
J/ψ photo production

J/ψ-007 [Nature 615 (2023) 7954, 813-816]   GlueX [arXiv:2304.03845]

- Two (distinct) approaches:
  - t-channel partial waves ← $l_{max} \leq 2$ mass radius, gravitational form factors, etc.
  - s-channel partial waves ← s-channel thresholds



Kharzeev et al. (1999), Brodsky et al (2001) Ji et al.Guo et al. (2021) Z, Mamo, Zahed, (2020)



Du et al [Eur. Phys. J. C 80 (2020) 1053]

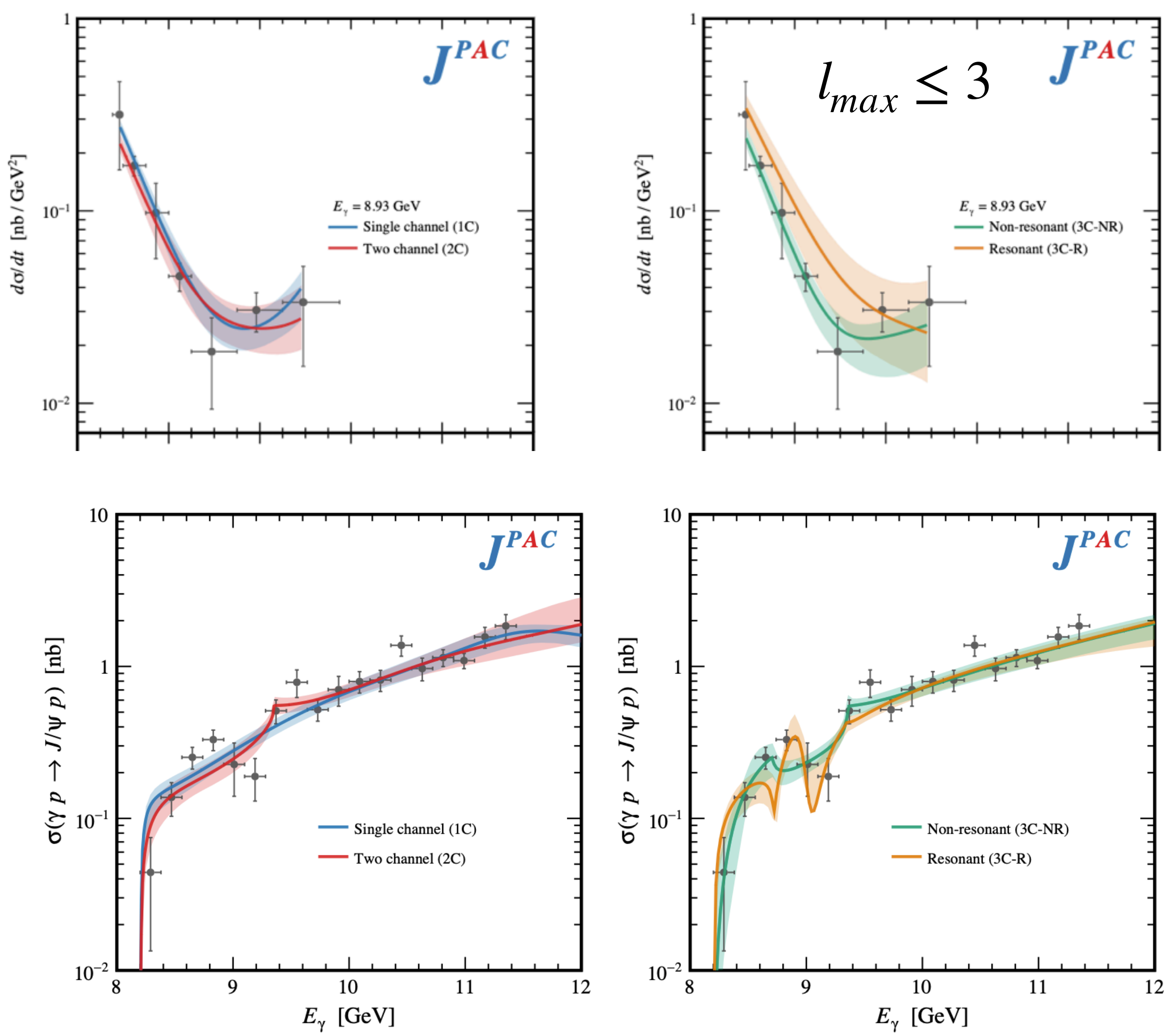


FIG. 1: Fit results for the integrated cross section compared to GlueX data from [37]. Bands correspond to 1σ uncertainties from bootstrap analysis.

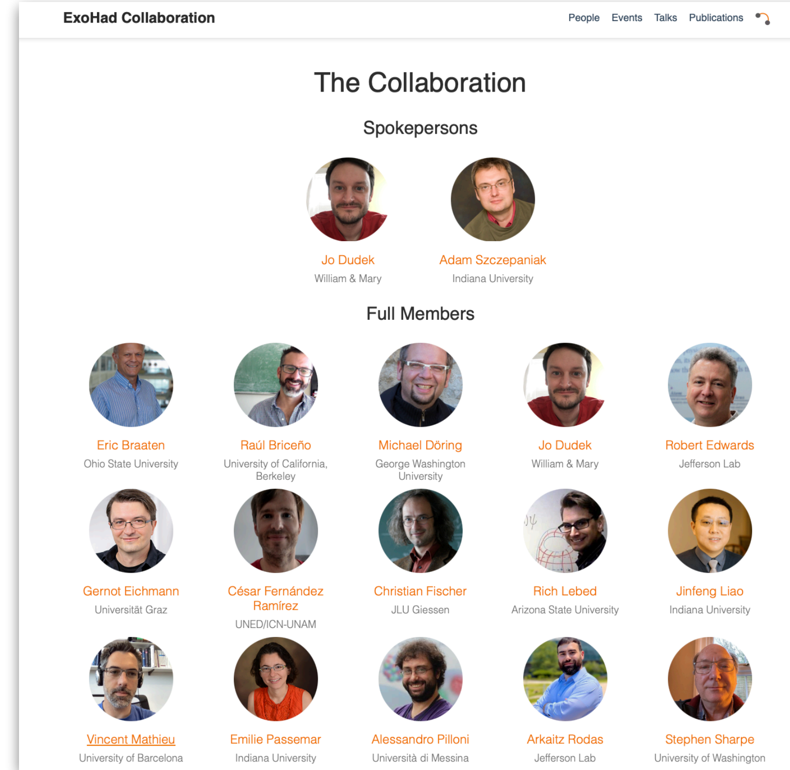
D.Winney: "Dynamics of J/ψ photoproduction near threshold"
Session: Exotic Hadrons and Candidates"
Monday at 14:00

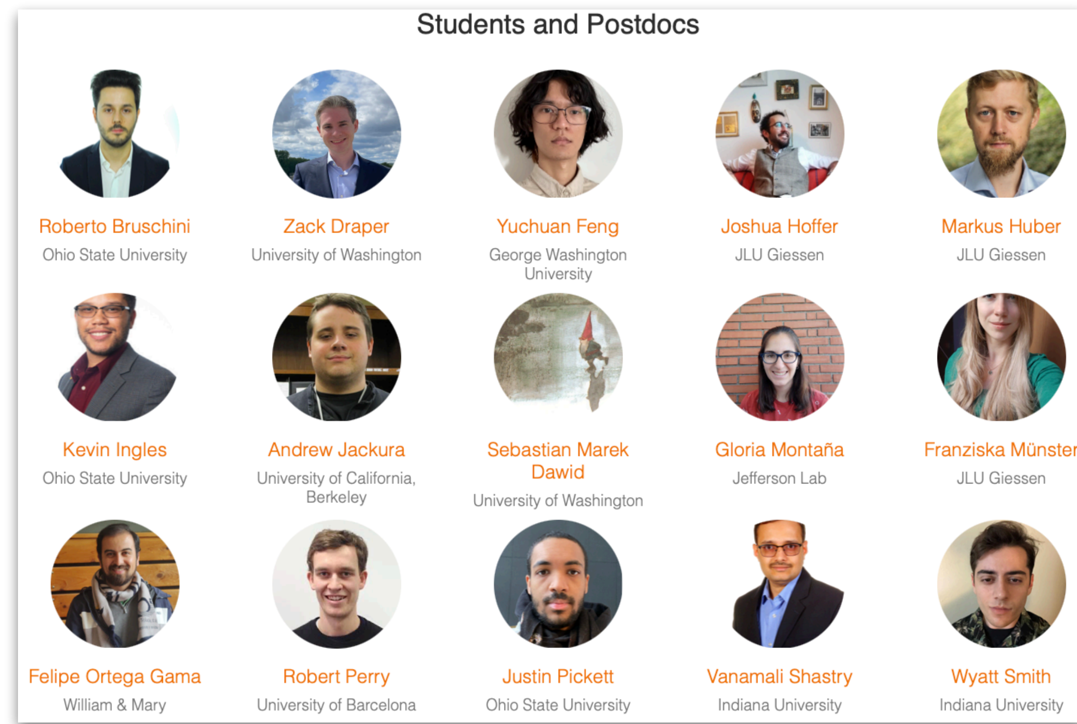
What's in the future

ExoHad

Exotic Hadrons Topical Collaboration

- Next 5 y : Complete development of the tools and techniques necessary to extract physics results from the GlueX and CLAS experiments.
- Beyond 5y: Develop a broad program of XYZP studies relevant to the current measurements at accelerators and the future electron-hadron facilities, including the EIC and the upgraded Jefferson Lab.
- All along : Support the growth of the QCD spectroscopy community by investing in the education of next generations.





JPAC

- **predicting** exotic and non-exotic meson resonances and their properties from lattice QCD;
- reliably **extracting** exotic and non-exotic meson resonances and their production and decay properties from experimental data sets;
- **interpreting** both the experimental and theoretical results.