Hadron Spectroscopy Studies at JPAC

Adam Szczepaniak (IU/JLab)

- A brief update on JPAC activities
- JPAC approach to data analysis and interpretation
- Moving towards determination of hadron spectrum exotica

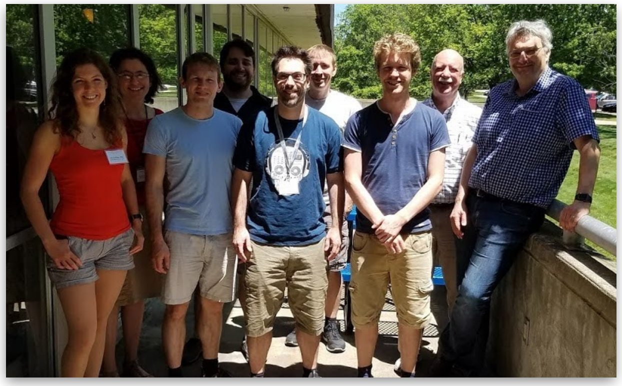
JPAC

EXOHAD
EXOTIC HADRONS TOPICAL COLLABORATION

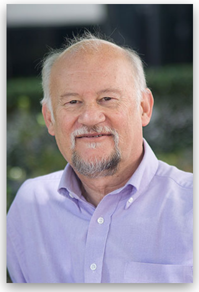
JPAC Brief History

- Established in 2013 to develop theory and phenomenology in support of experimental program at JLab12. Has grown into international effort that liaisons between theory and experiment.

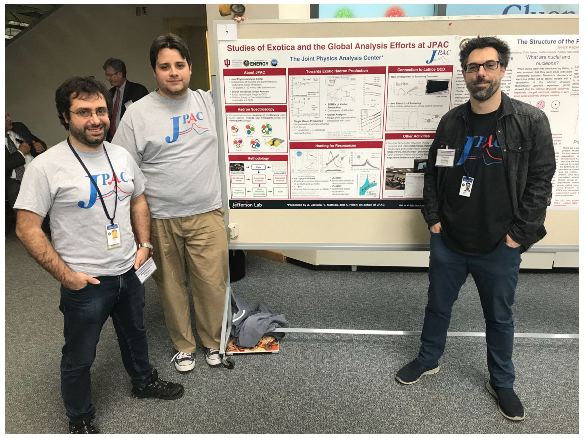
- co-organized over 30 international conferences, including its own "Future Directions in Spectroscopy Analysis” series, summer schools, graduate courses, published over 200 papers

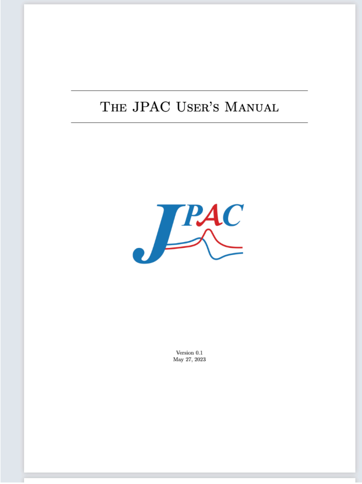


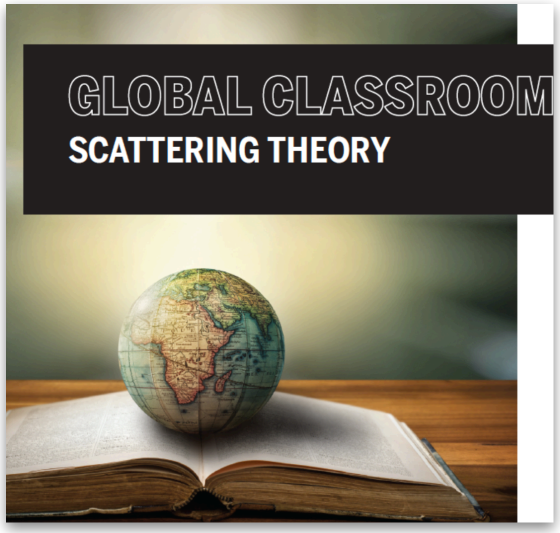
JPAC ca. 2018



Mike Pennington
(1946-2018)







- Tuesday’s JPAC meetings have run continuously for the past 10 years (record over 8h)

- Over ~40 researchers have been associated with JPAC

New Faculty/ Scientists

- JPAC's priority is to provide an intellectually stimulating environment and create carrier opportunities for its members

- We adopted a horizontal management structure, decisions made by consensus with shared responsibilities and benefits (e.g. publication policy)

Vincent
(Prof. U.Barcelona)

Misha
(Prof. Ruhr U.)

Lukasz
(Prof. AGH U.)

Andrew
(Prof. W&M)

Sergi
(Prof. U.Barcelona)

Alessandro
(Prof. U.Messina)

Miguel
(Sc.. IFIC Valencia)

Arkaitz
(Prof. ODU)

2024 PhD's

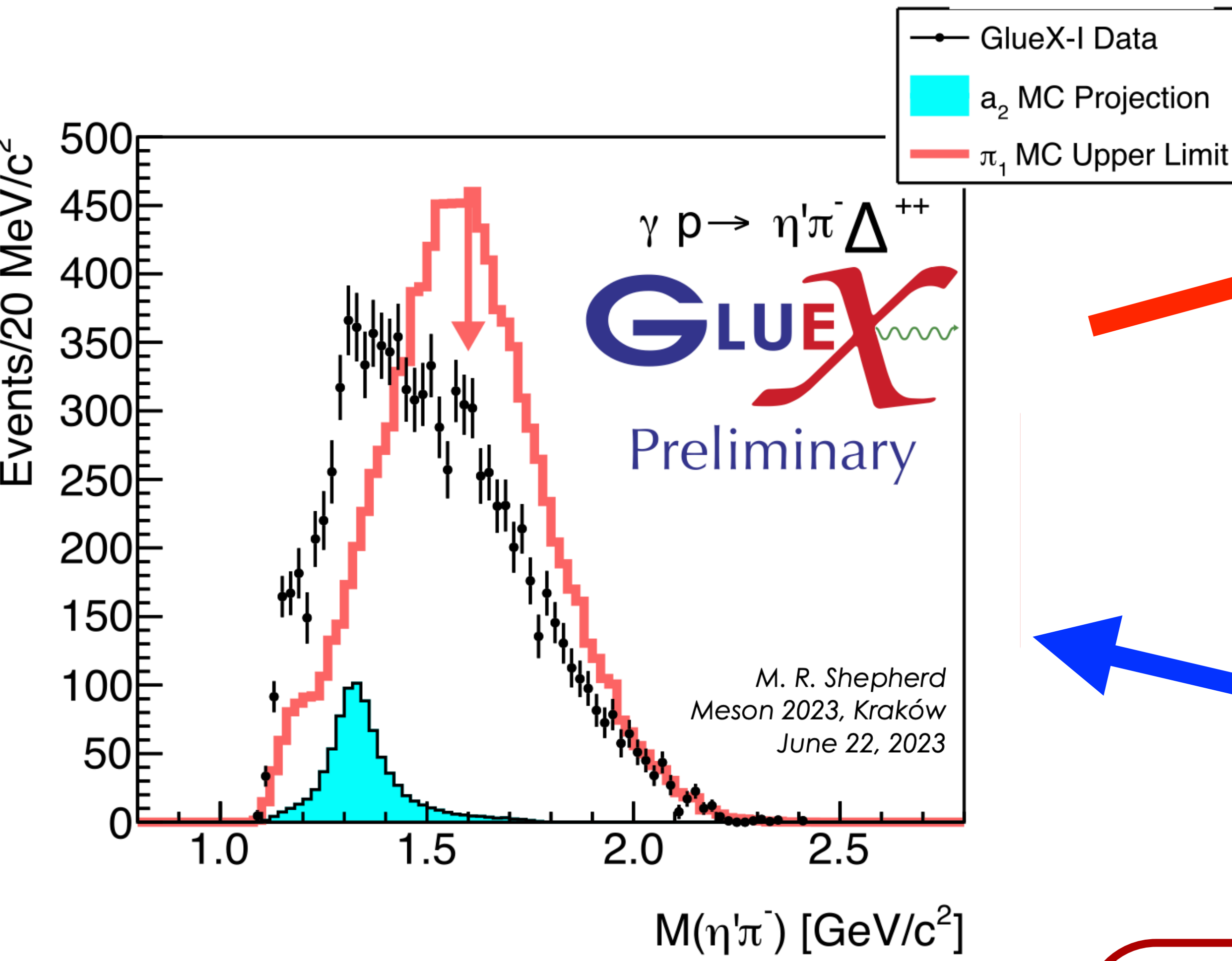
Wyatt
(Postdoc Berkeley)

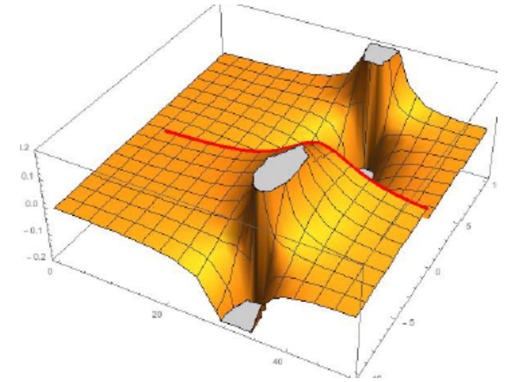
Nadine
(Postdoc U.Barcelona)

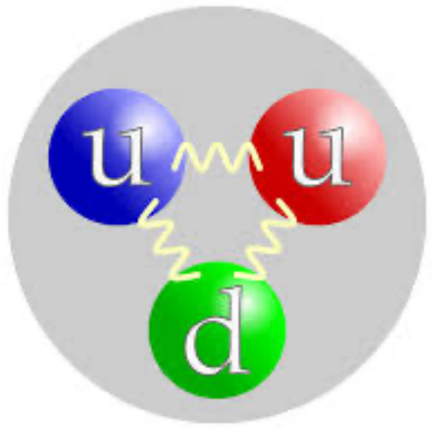
Astrid
(Sc.. Bosch)

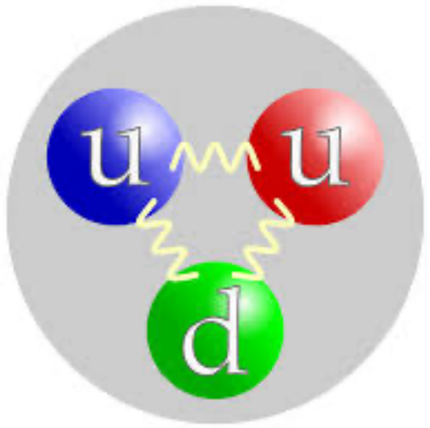
Bridging Experiment and Theory

Make S-matrix theory rooted hypotheses : minimal bias









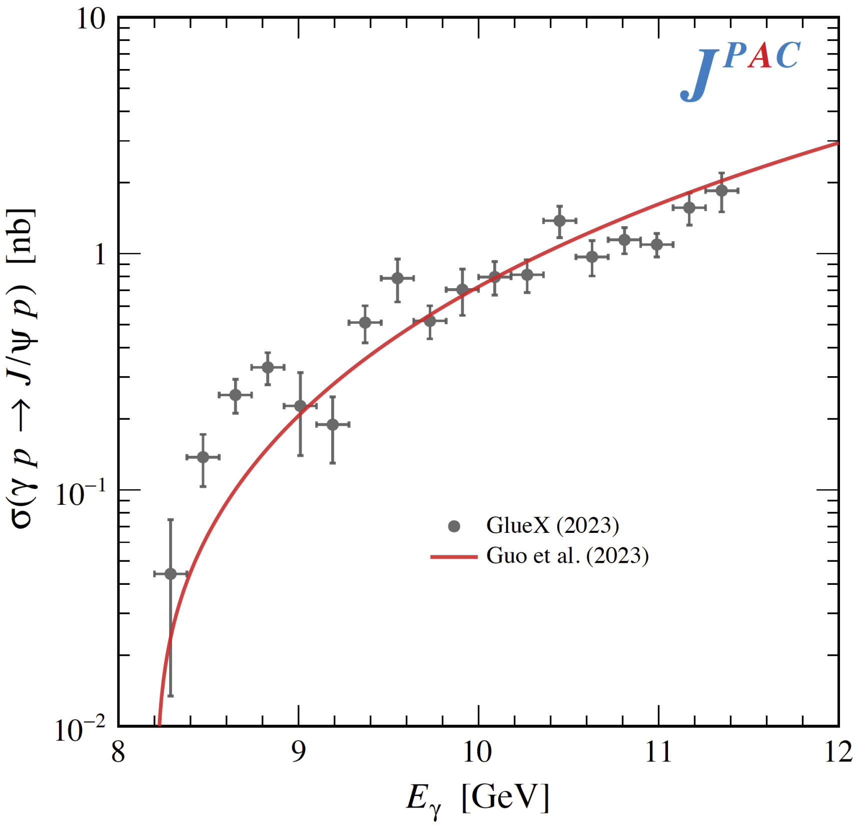
Make models and compare with data: difficult to avoid bias

$\gamma p \rightarrow J/\psi p$

Gluonium exchange (mass radius, $T^{\mu\nu}$, VMD…)

t-channel partial wave series with low spins (e.g. $J_{max} = 2$) implies smooth energy dependence

$$A(s,t) = \sum_{J=0}^{J_{max}\to\infty(?)} f^J_{\lambda_i}(t)\, d^J_{\lambda'\lambda}(\theta_t)$$



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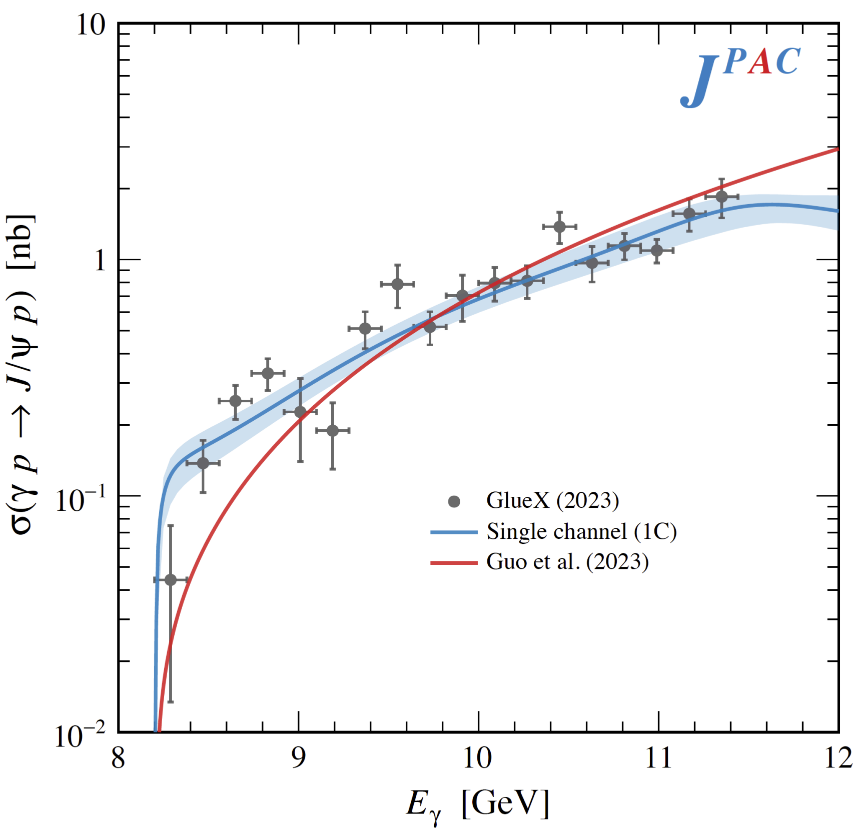


Near threshold s-channel partial wave series is more natural

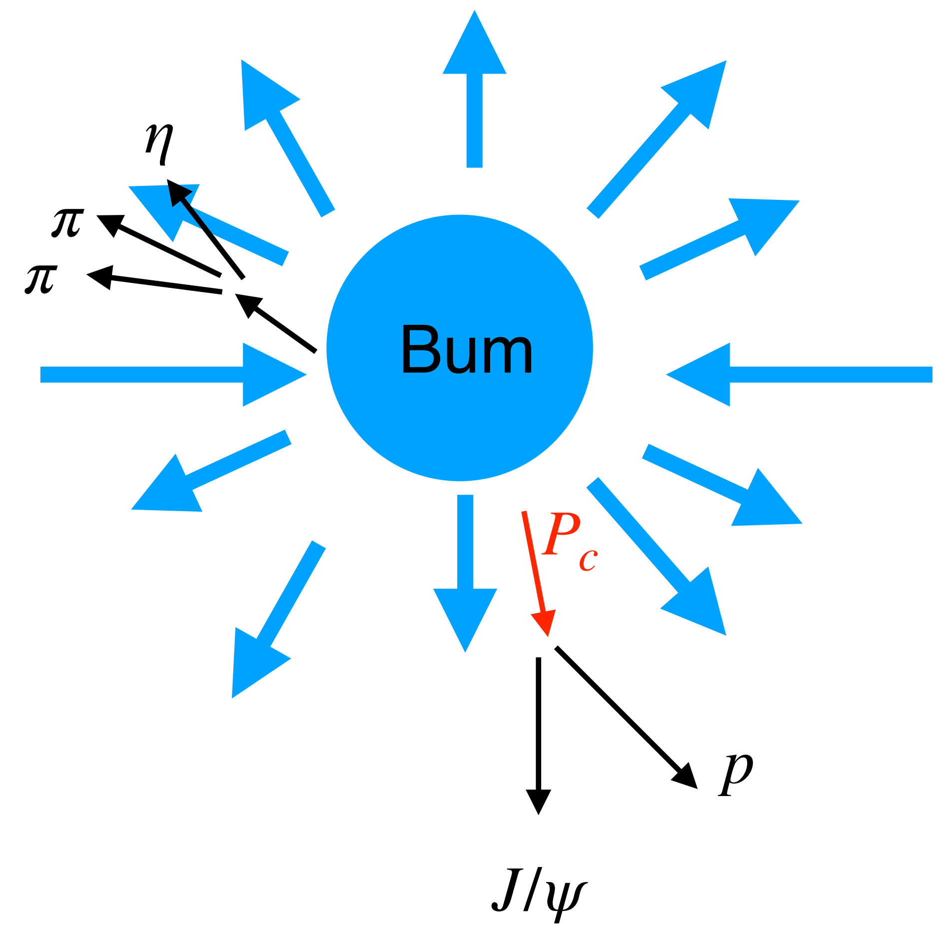
$$A(s,t) = \sum_{J=0}^{J_{max}=finite\ OK} f^J_{\mu_i}(s) d^J_{\mu'\mu}(\theta_s)$$

Explore t vs s channel p.w. series, fit the data and interpret the corresponding p.w. amplitudes in terms of microscopic dynamics (e.g. breakdown of VMD)
More data needed !

D.Winney et al. (JPAC, 2023)
Combined analysis of J/ψ 007 and GlueX

Uniqueness of JLab for spectroscopy

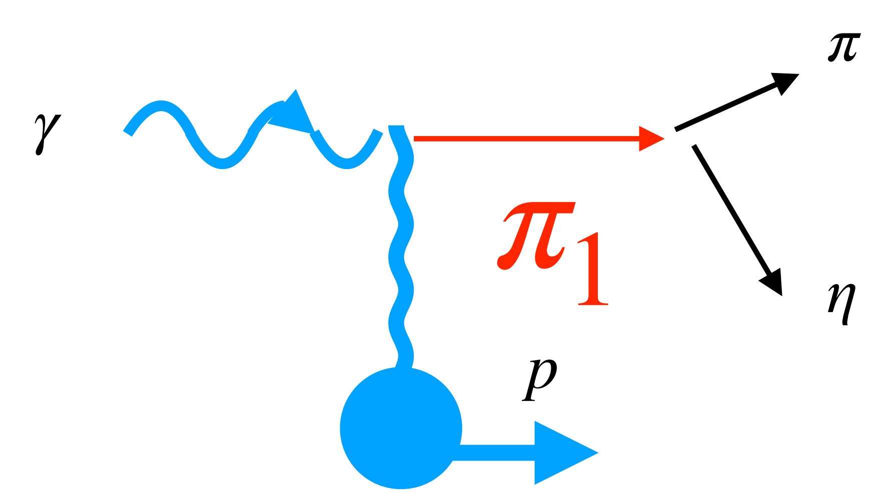
Majority of hadron exotics spotted in colliders.
Very few were seen in more then one setting

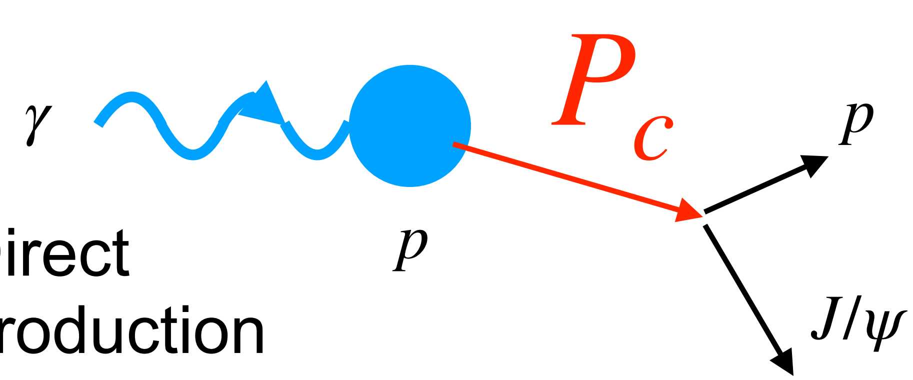


Fixed target with well tuned E_γ :

Full exclusivity
Low multiplicity
Direct production and peripheral production are calculable
Resonances can be well separated from kinematic effects
Significant rapidity gap enables to separate beam from target fragmentation

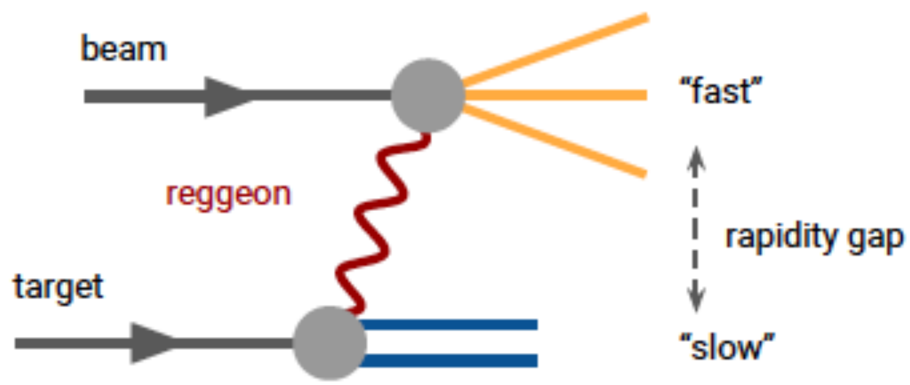
Peripheral production





Direct production

Peripheral Production



- Factorization

$$A_{\lambda_i}(,t) = \beta^{Top}_{\lambda_1,\lambda_{\bar{3}}}(t)\beta^{Bottom}_{\lambda_1,\lambda_{\bar{4}}}(t)G(s,t)$$

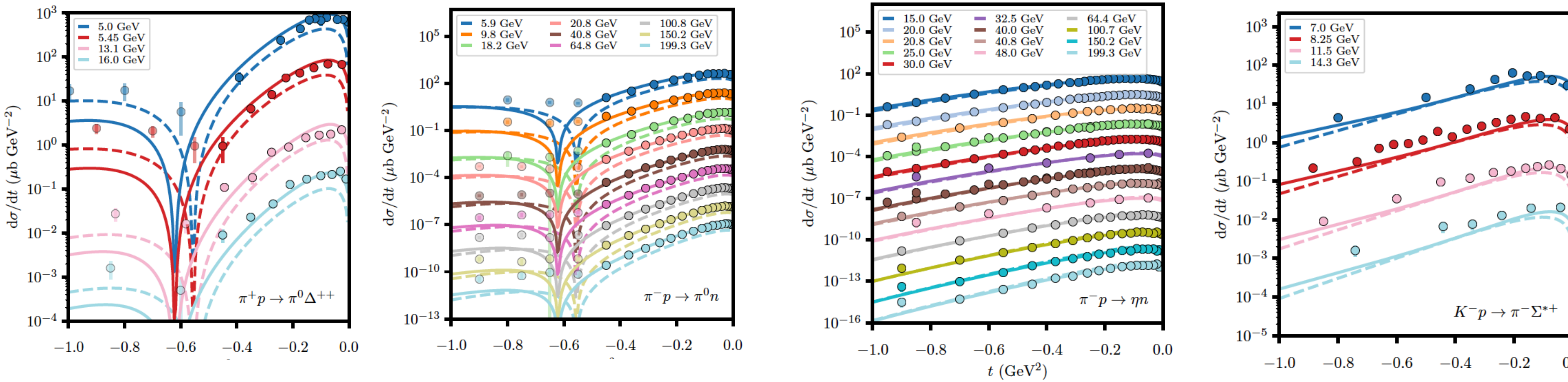
- Shrinkage of the forward peak $G(s,t) \sim exp(b\log(s)t)$

- Phases constrained by unitarity

- Residues (β's) related to observables e.g. $\beta^2(\gamma b_1, R_\pi) \sim \Gamma(b_1 \to \gamma\pi)$

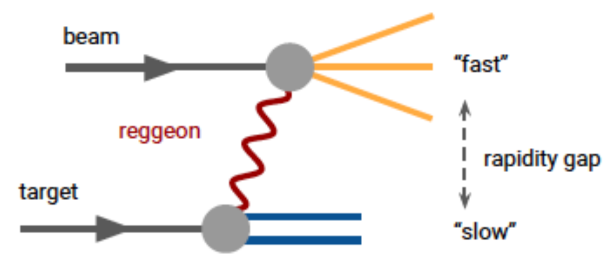
- Corrections O(1/log(s)) can be formalized within an EFT

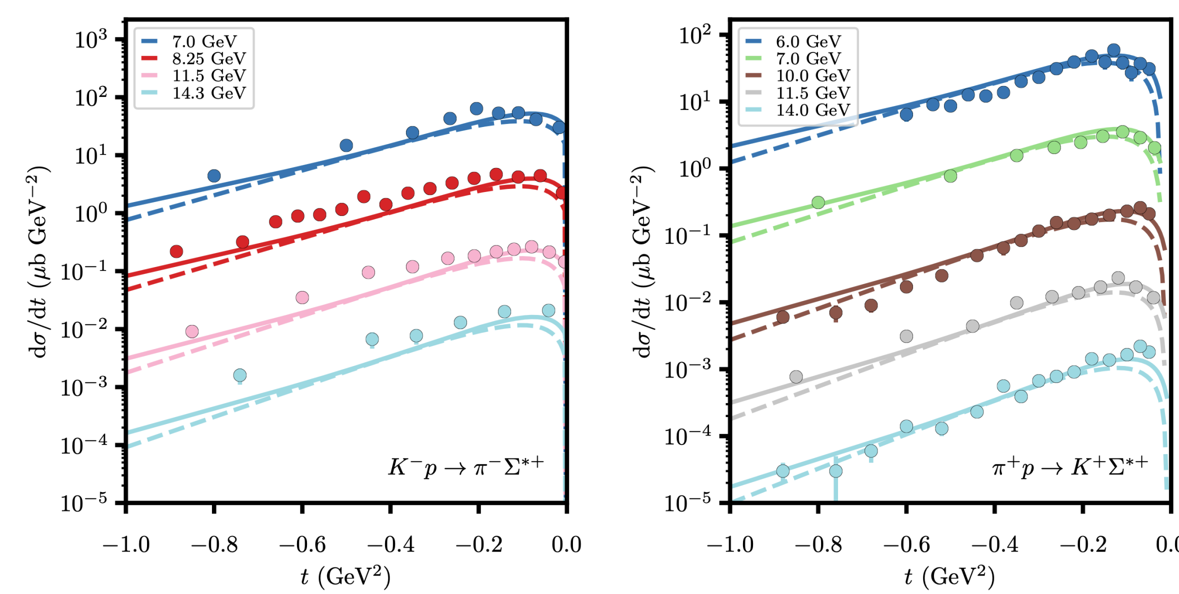
Global Regge pole of CEX (no P no π)



"ρ" exchange dip at ($t \sim -0.5 GeV^2$)

"a_2" exchange





(a) $K^- p \to \pi^- \Sigma^{*+}$

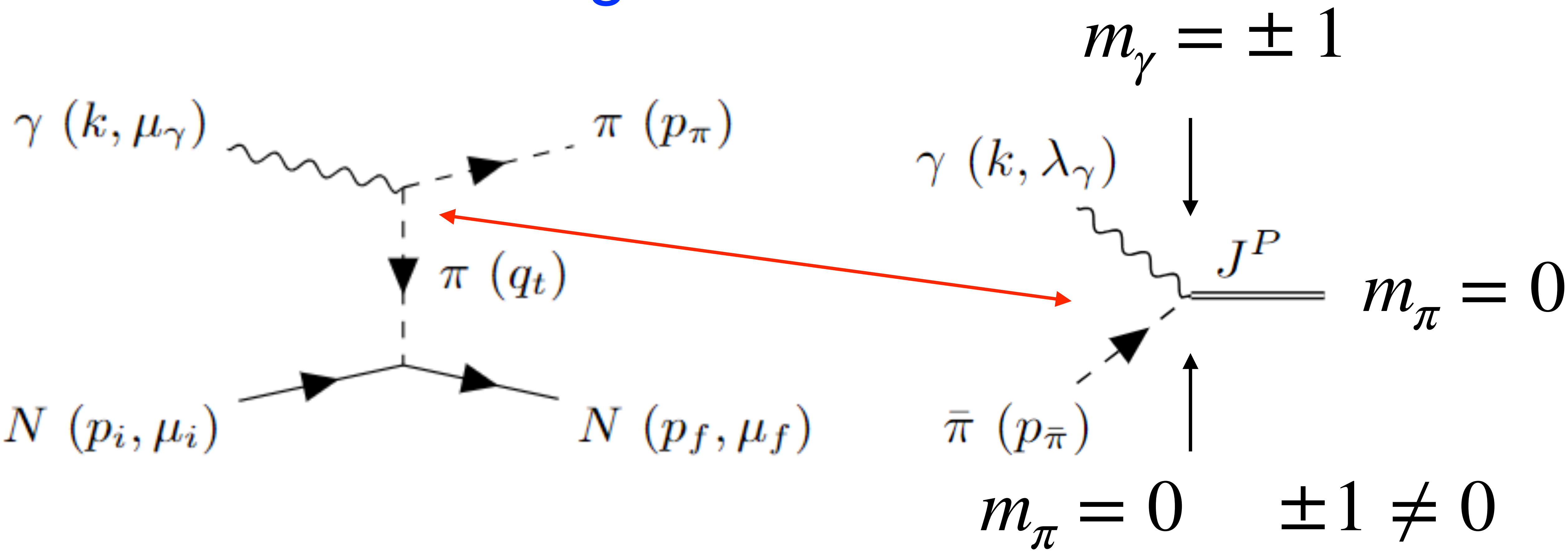
(b) $\pi^+ p \to K^+ \Sigma^{*+}$

Regge poles well describe peripheral production at CEBAF energies

"K/K^*" exchange

Data =1271 points, N_{par} = 6 SU(3) couplings, 1 mixing angle, 2 exp. slopes) *J.Nys et al. (JPAC) 2018*

Fun with π exchange



Naively there is no π exchange ! 🤔

$$A_{\lambda_i}(s,t) = \sum_J (2J+1) A^J_{\lambda_i}(t) d^J_{\lambda_{\bar{N}}-\lambda_N,\lambda_\gamma}(\theta_t) \sim A^0_{\lambda_i}(t)\, d^0_{\lambda_{\bar{N}}-\lambda_N,\pm 1} \sim 0$$

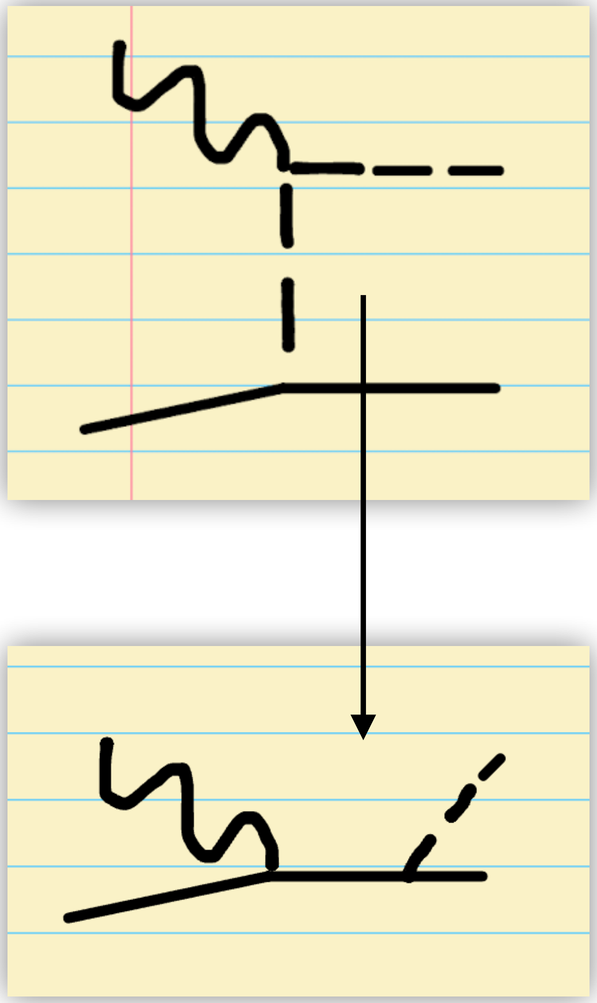
Regge : A^J is analitic în J !

$$A_{\lambda_i}(s,t) = \sum_J (2J+1) A^J_{\lambda_i}(t) d^J_{\lambda_{\bar{N}}-\lambda_N,\lambda_\gamma}(\theta_t)$$

$$A^J_{\lambda_i}(t) \sim \frac{1}{J}\frac{1}{J-\alpha_\pi(t)} \qquad J\frac{t-m_\pi^2}{s-u}$$

J=0 kinematical fixed pole

π pole



- The J=0 fixed pole corresponds to s/u -channel nucleon exchange :No need to mix t and s/u channel diagrams !
- "Regge knows" about current conservations"

G.Montana et al. (JPAC, 2024)

Systematic analysis of the π_1 at JLab

1 We know π_1 decay characteristics (mostly done)

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	$1564 \pm 24 \pm 86$	$492 \pm 54 \pm 102$

A.Rodas et al. (JPAC) 2019

	thr./MeV	$\lvert c_i^{\text{phys}}\rvert$/MeV	Γ_i/MeV
$\eta\pi$	688	$0 \to 43$	$0 \to 1$
$\rho\pi$	910	$0 \to 203$	$0 \to 20$
$\eta'\pi$	1098	$0 \to 173$	$0 \to 12$
$b_1\pi$	1375	$799 \to 1559$	$139 \to 529$
$K^*\overline{K}$	1386	$0 \to 87$	$0 \to 2$
$f_1(1285)\pi$	1425	$0 \to 363$	$0 \to 24$
$\rho\omega\{^1P_1\}$	1552	$\lesssim 19$	$\lesssim 0.03$
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$f_1(1420)\pi$	1560	$0 \to 245$	$0 \to 2$
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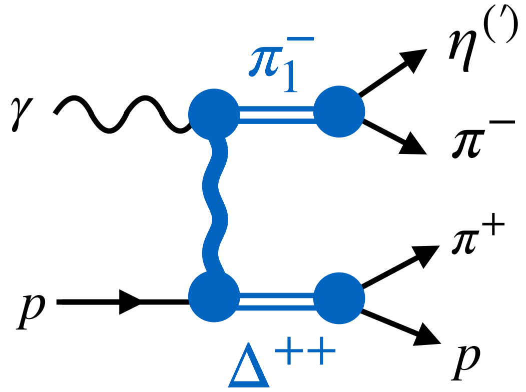
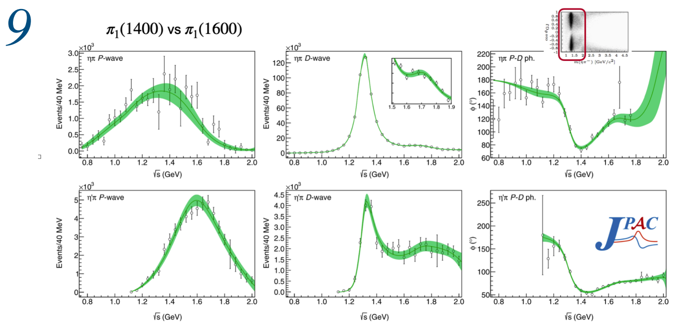
A.Woss et al. (HadSpec) 2021





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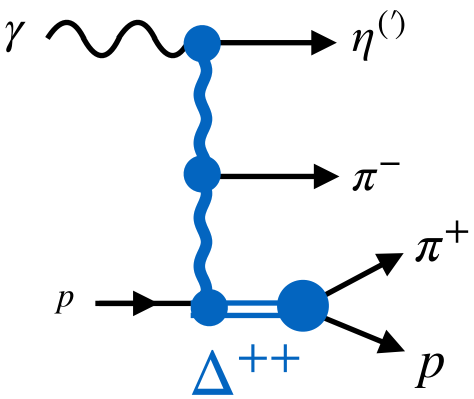

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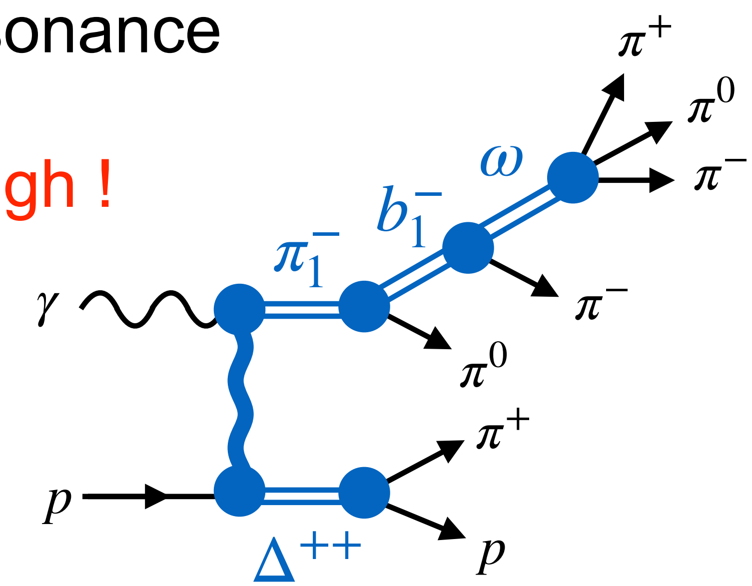
(In progress) Major breakthrough !



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INDIANA UNIVERSITY Jefferson Lab

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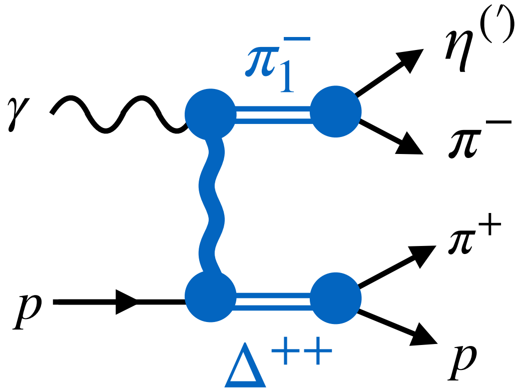

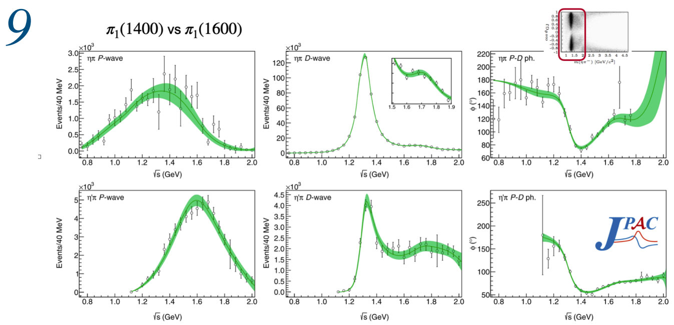

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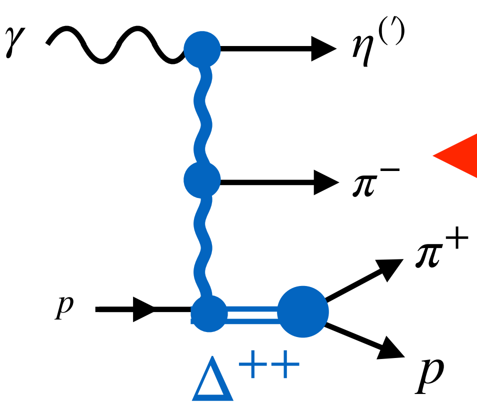

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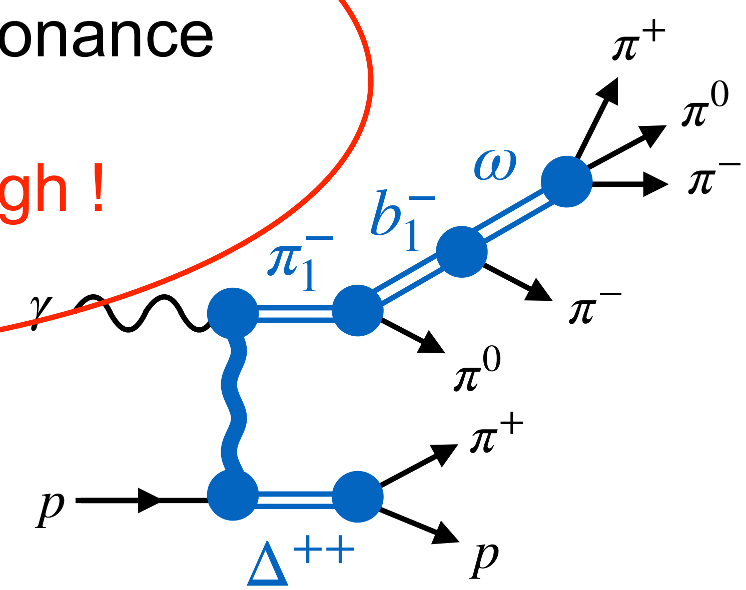
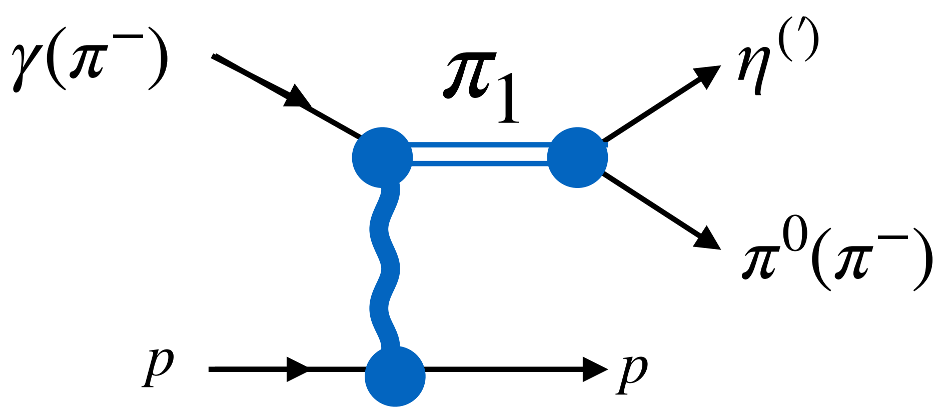
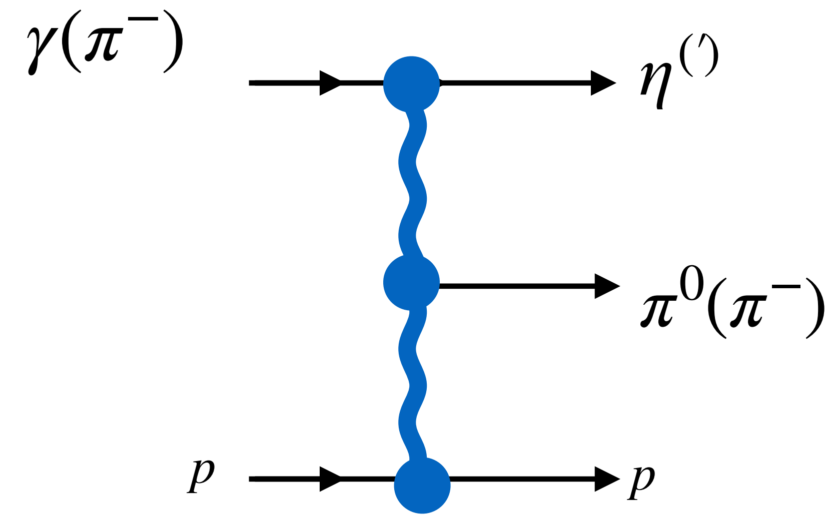


4.Extend to include other channels (in progress)

Dispersion relations for 2-3 process

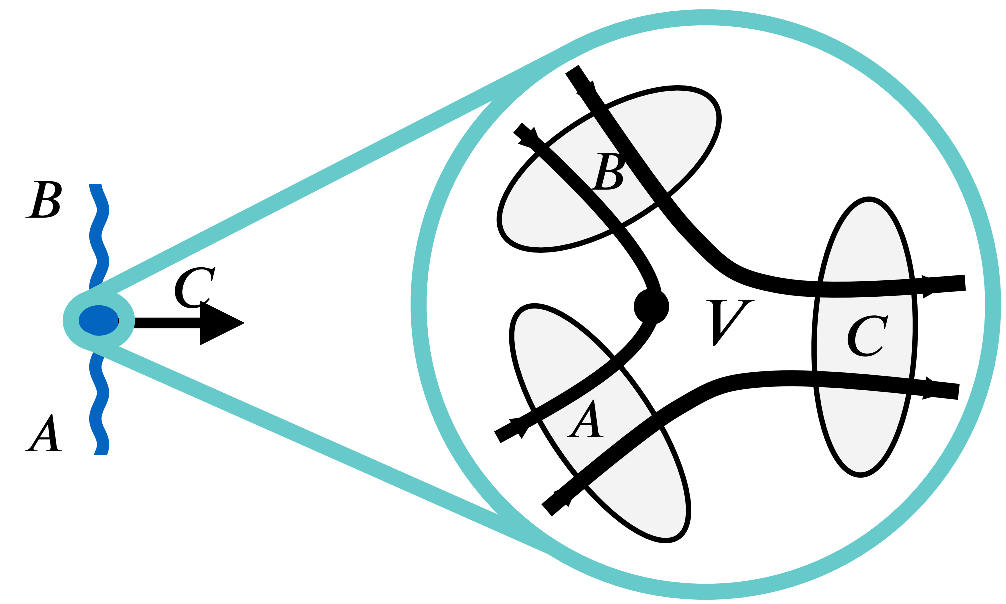


Dispersion relations , Finite Energy Sum Rules, etc



GlueX/(COMPAS) analysis in progress

The existing models of the Double Regge exchange suffer from pathologies (infinite narrow resonances) We have "understood" how to construct DR amplitudes without such pathologies



Enables comparison with microscopic models and lattice

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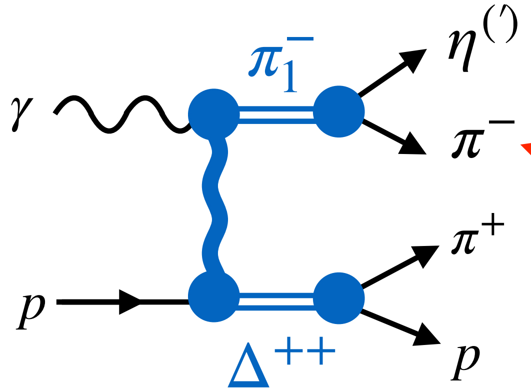

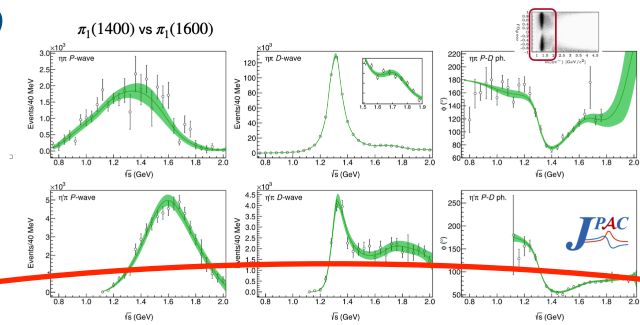

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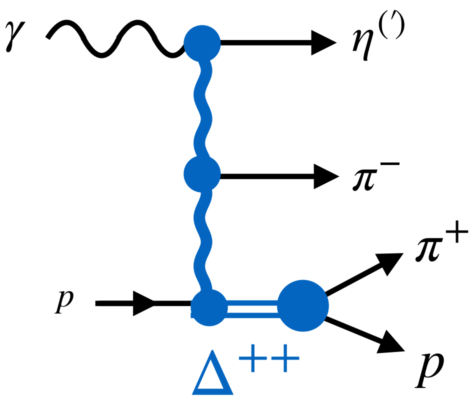

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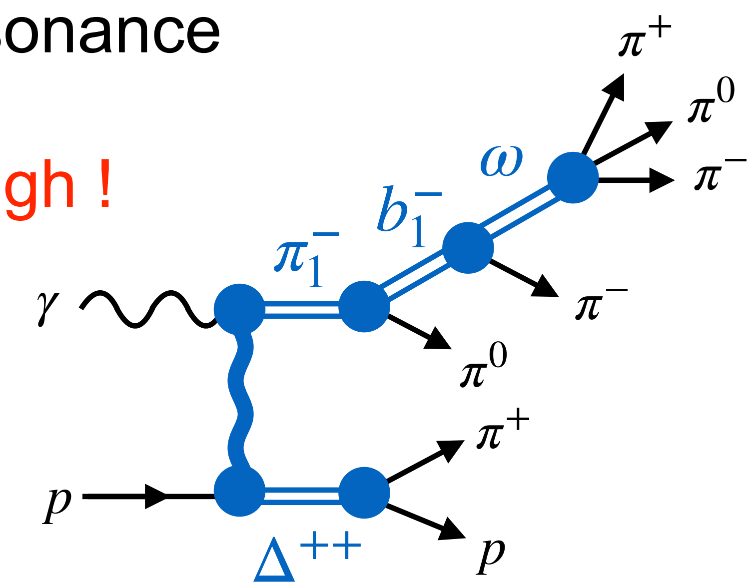
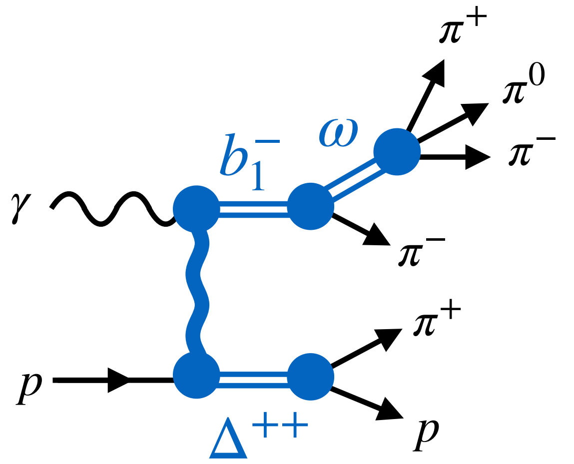


Resonance production via single Regge exchange

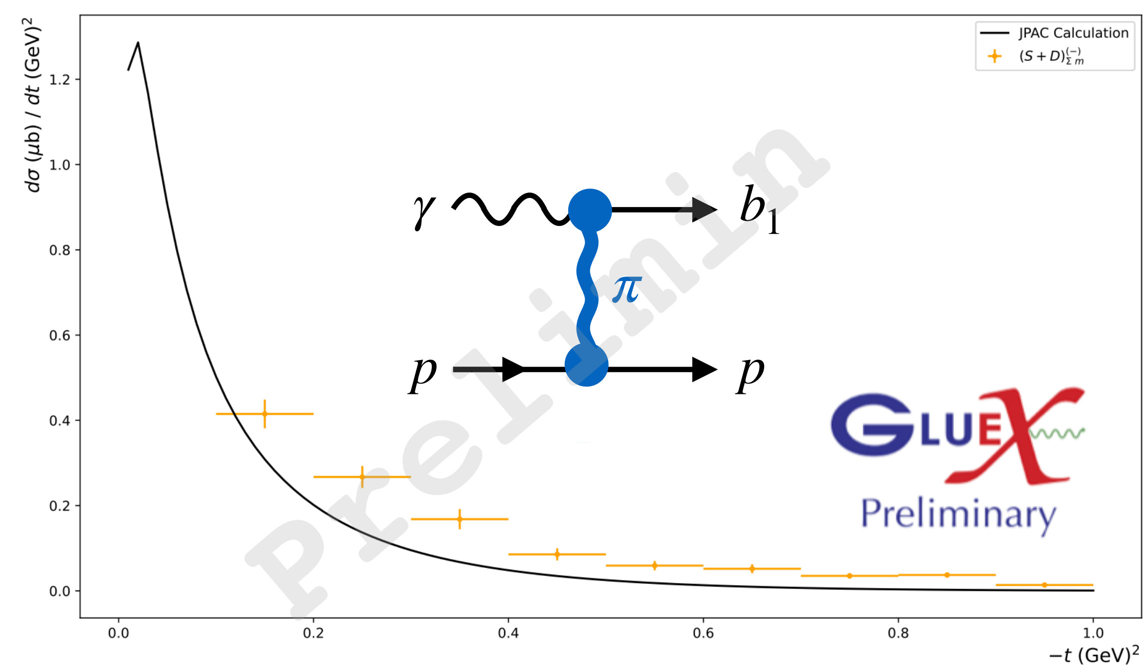
Main exotic decay is $\pi_1 \to b_1\pi$

Need first to understand b_1 photoproduction



$\gamma p \to b_1^- \Delta^{++}$ $\gamma p \to b_1^0 p$

In the neutral channel $\gamma p \to b_1^0 p$
GlueX PWA shows (very) small contribution from unnatural exchange compares to natural (?)



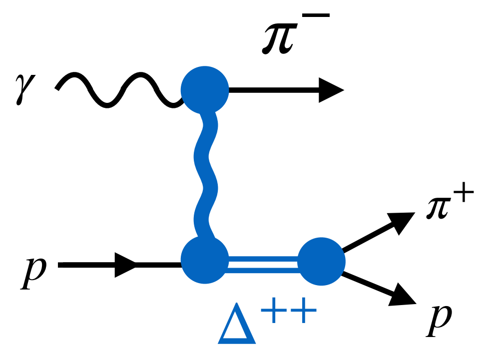
Model/Decay chain:

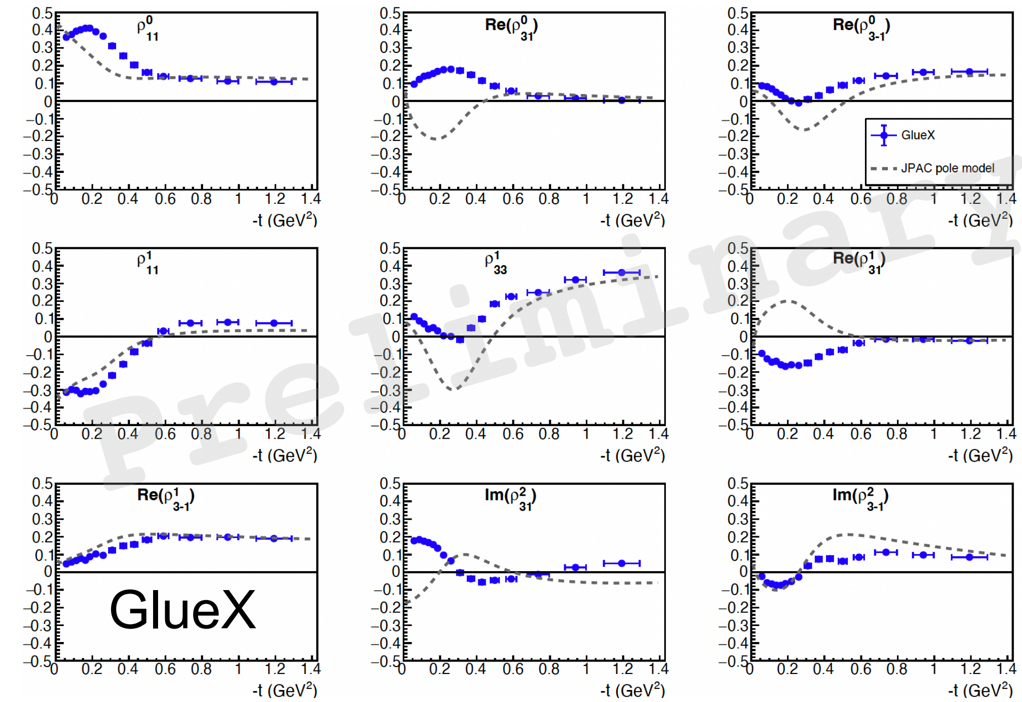
$$A_{\lambda_\gamma,\lambda_1,\lambda_2} = \sum_{\Lambda=-1}^{1} \sum_{\lambda_\Delta=-\frac{3}{2}}^{\frac{3}{2}} V_{\lambda_\gamma,\Lambda;\lambda_1,\lambda_\Delta}(s,t) \sum_{\lambda=-1}^{1} F_\lambda D^{J*}_{\Lambda,\lambda}(\Omega_\omega) Y^1_\lambda(\Omega_H) G \tilde{F}_{\lambda_2} D^{\frac{3}{2}*}_{\lambda_\Delta,\lambda_2}(\Omega_p)$$

Pion exchange cross-section in agreement (prediction, not fit!) with preliminary data

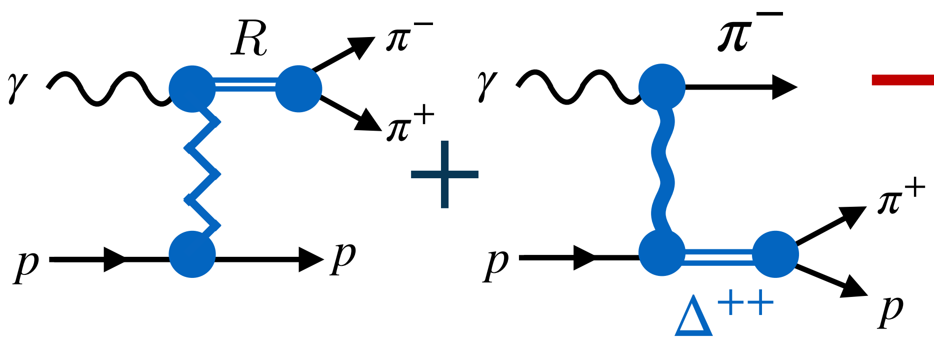
Towards complete understanding of photoproduction

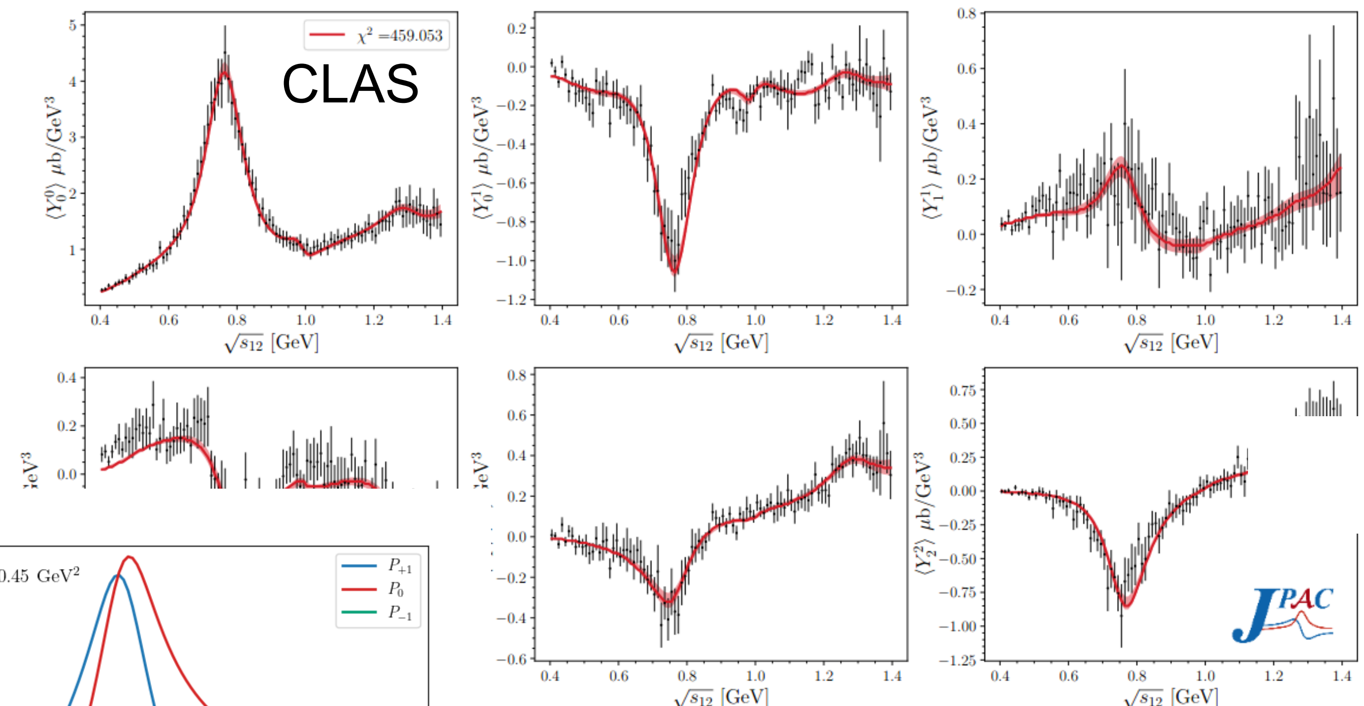
Understanding Δ^{++} production is underway





Two-pion photo production project almost completed (impressive data agreement)

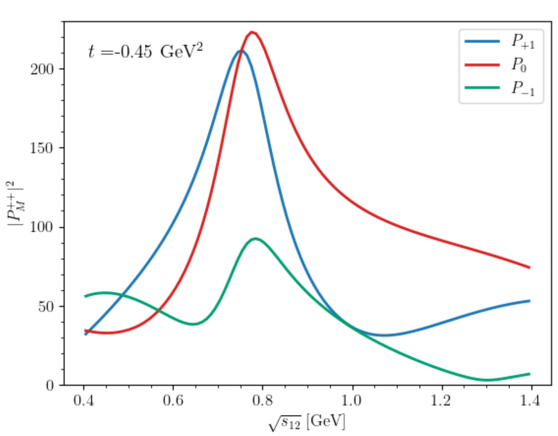




) for $L = 0, 1, 2$ and $M = 0, \ldots L$ for $E_\gamma = 3.7$ GeV and $t = -0.95$ GeV^2.

High quality data from CLAS, more expected from CLAS12 and GlueX

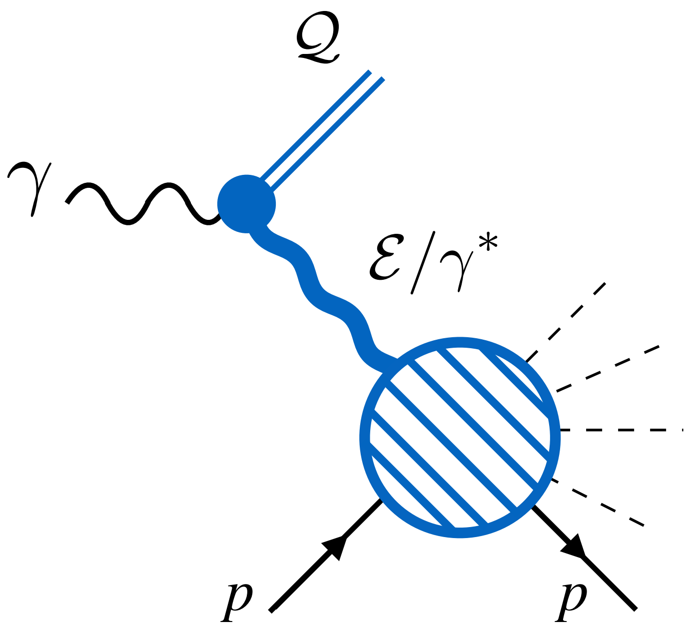
Hierarchy of P-waves for various helicities, determined production dynamics that gives rise to other helicity structures for $|t| \gtrsim 0.45$ GeV^2

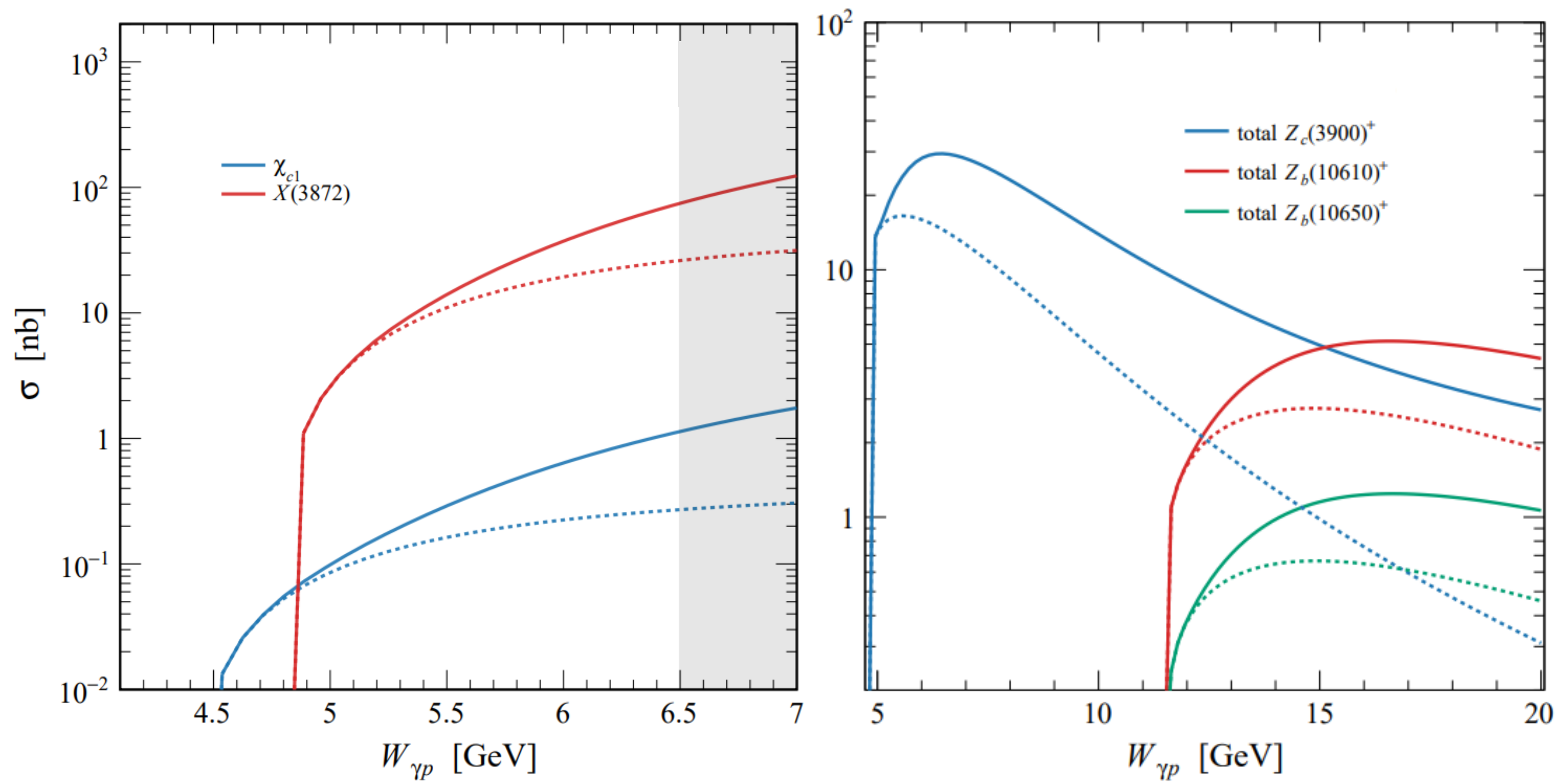


L.Bibrzycki, et al. (JPAC) 2024

XYZ searches in future facilities: Photoproduction (JLab22, EIC)

These predictions suggest that the extraction of exotics at JLab 22 is a possibility
(XZ searches might be better at JLab 22, Y searches better at EIC)





Semi-inclusive processes have more backgrounds than exclusive ones, but higher cross sections! Ideal for the first observation

Predictions are based on one-particle exchange mechanisms and are likely a conservative underestimation of total production rates

D.Winney et al. (JPAC) (2023,2024)

Summary

- (Quasi) elastic production of meson resonances (including exotics) well described in terms of an EFT, Regge theory : Verified in GlueX and CLAS12 data

- Use Regge theory is well advances to correlate resonance production with resonance decays, important to constrain unknown resonance parameters

- JPAC has developed a unique environment to foster collaboration between theory and experiment. Working with GlueX, CLAS12 and other international efforts is on track to provide best tools needed to interpret (exotic) spectroscopy data

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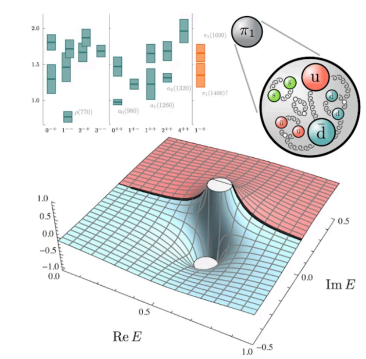
EXOHAD
EXOTIC HADRONS TOPICAL COLLABORATION

The Exo(tic) Had(ron) Collaboration started in 2023 to explore all aspects of exotic hadron physics, from predictions within lattice QCD, through reliable extraction of their existence and properties from experimental data, to descriptions of their structure within phenomenological models.



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