Amplitude Analyses for GlueX and CLAS12

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Universidad de Barcelona

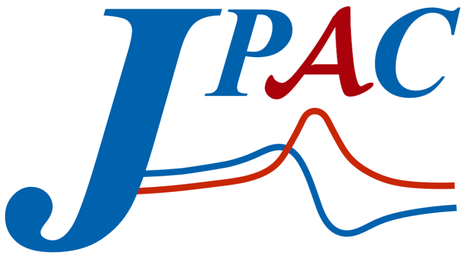
JPAC review

JLab November 2022

UNIVERSITAT DE BARCELONA

ICCUB EXCELENCIA MARÍA DE MAEZTU

Institut de Ciències del Cosmos



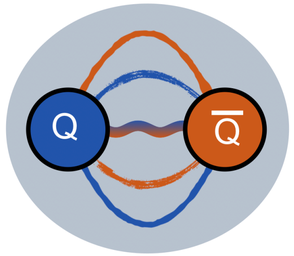
Joint Physics Analysis Center

Meson Spectroscopy at JLab

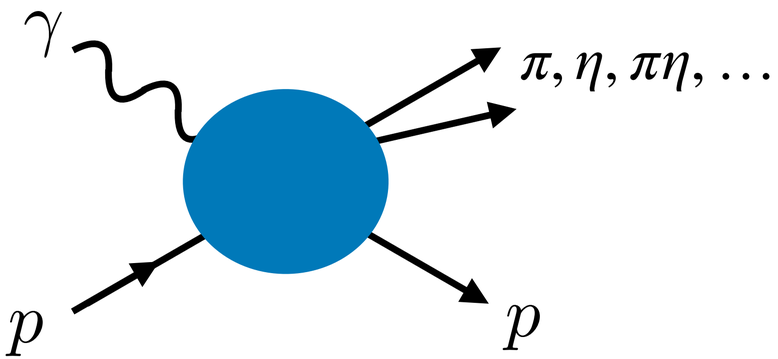
Photoproduction of mesons at $E_\gamma = 6 - 12$ GeV

Study photoproduction of mesons

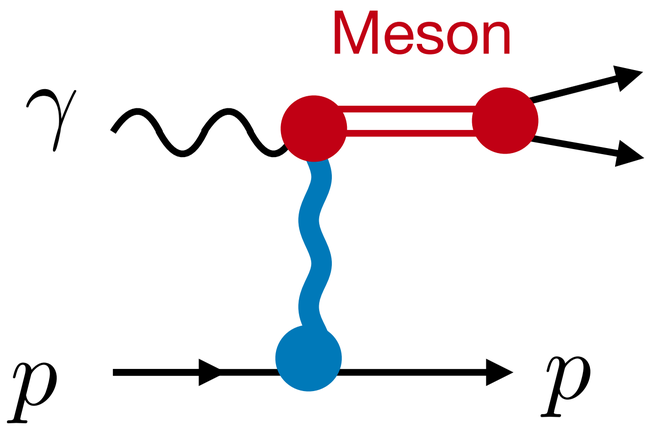
Search for exotic resonances



Special interest in mesons: Does the target factorize at JLab energies?



Factorization?

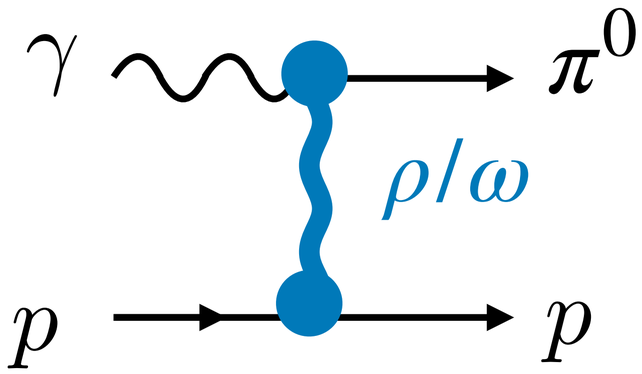


Single Pion Photoproduction

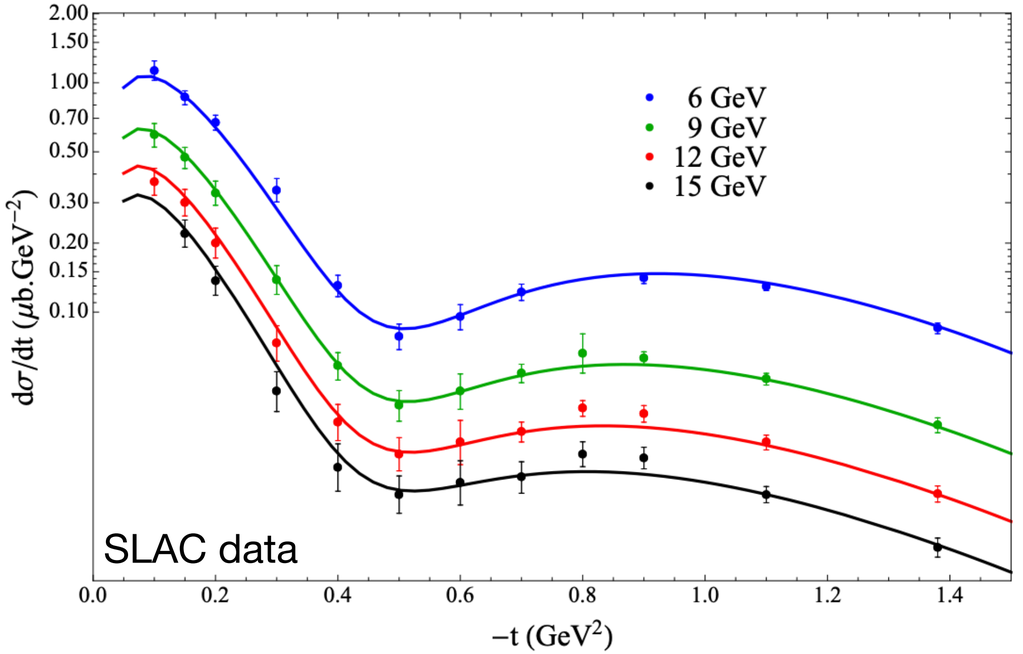
VM, Szczepaniak and Fox PRC92 (2015)

Production by Regge exchange implies known energy dependence

Excellent agreement between data and model



Regge-based model



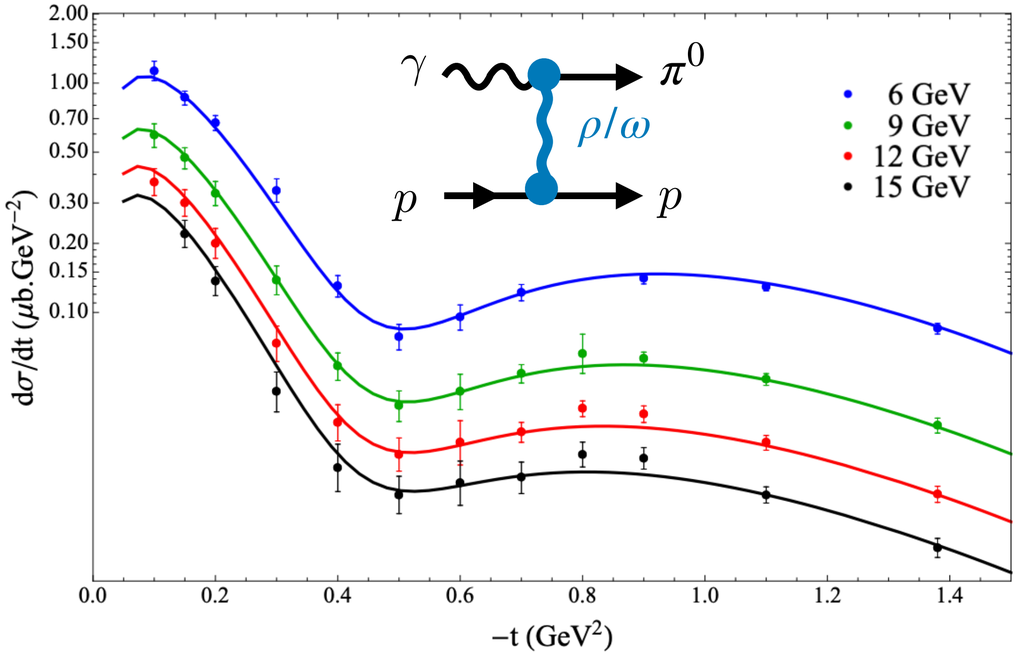
Single Pion Photoproduction

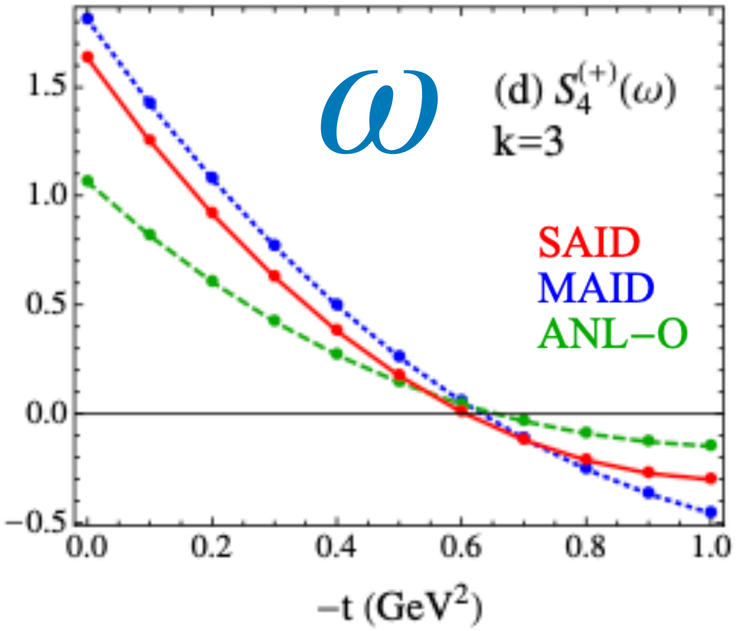
VM et al (JPAC) PRC98 (2018)

VM et al (JPAC) EPL122 (2018)

t dependence from baryon resonances and duality hypothesis (dispersion relations)

Dip in the cross-section induced by zero in ω exchange





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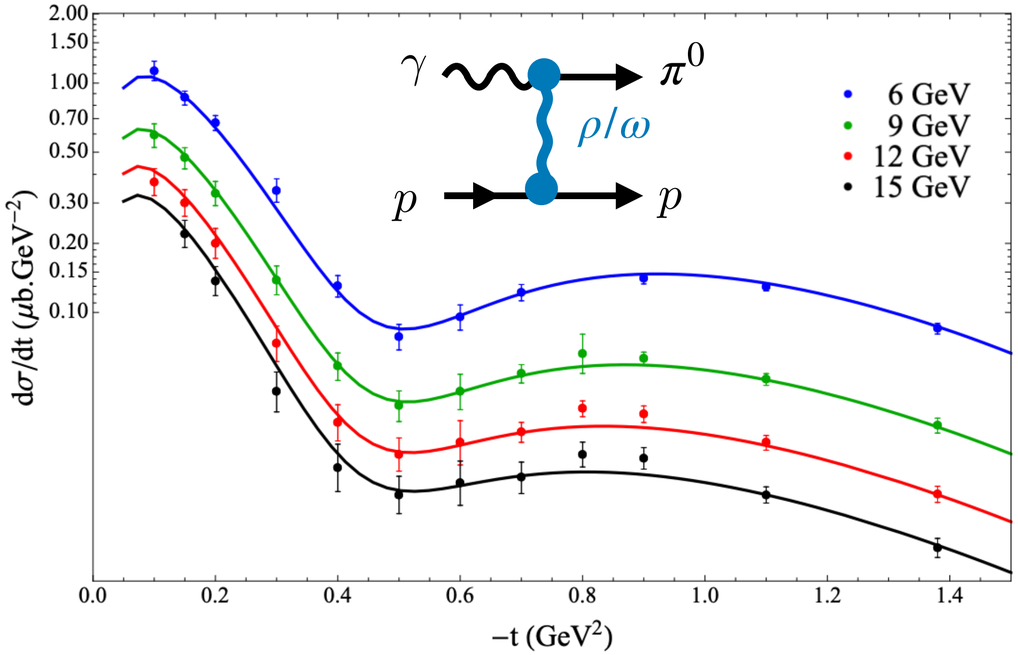
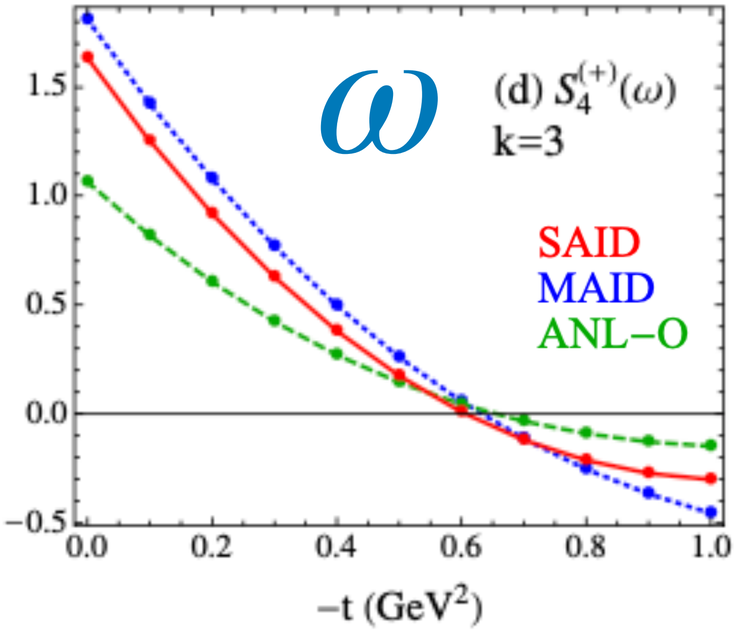
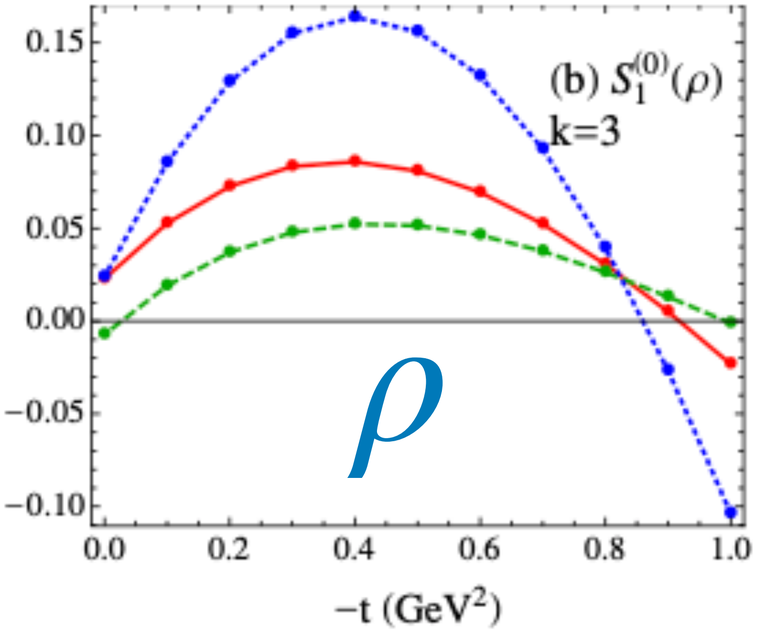
ρ exchange "fills the gap"



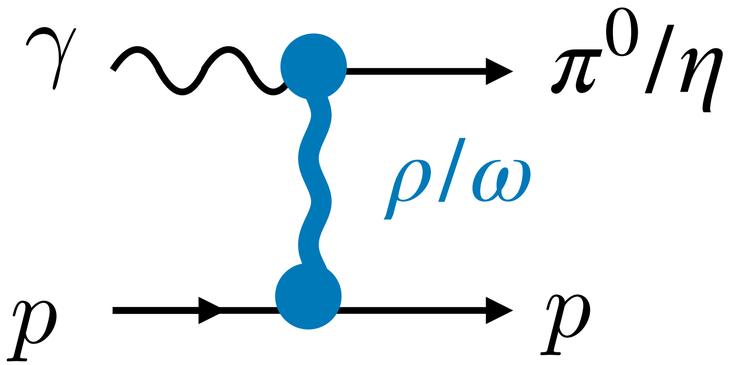




Single Eta Photoproduction

J. Nys et al (JPAC) PRC95 (2017)

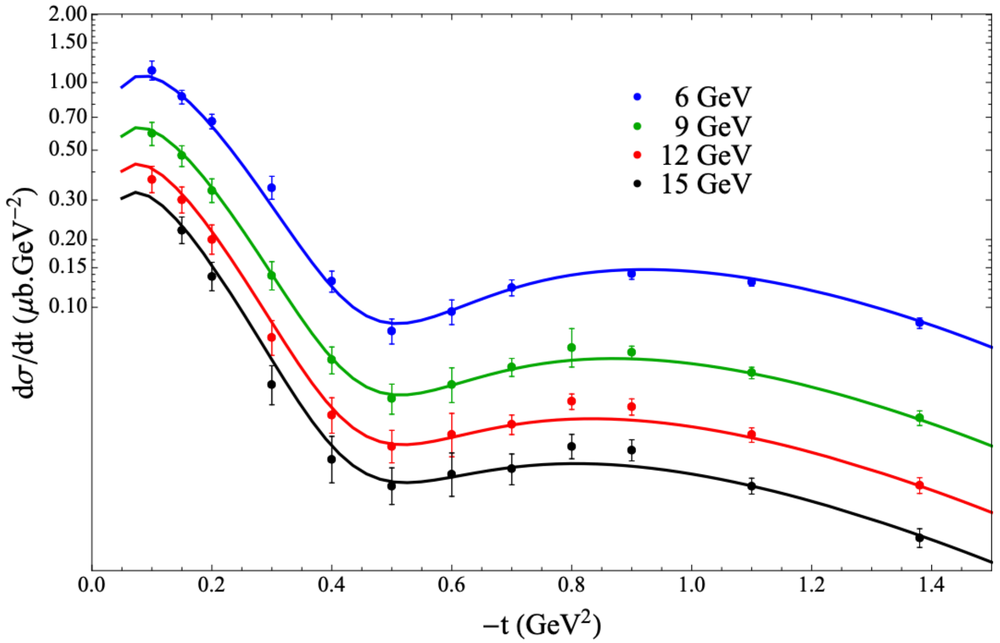
Regge based model for η photoproduction
with known energy dependence
and t dependence from duality



$$\pi^0 : \omega + \frac{1}{3}\rho$$

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

ω dominates and dips



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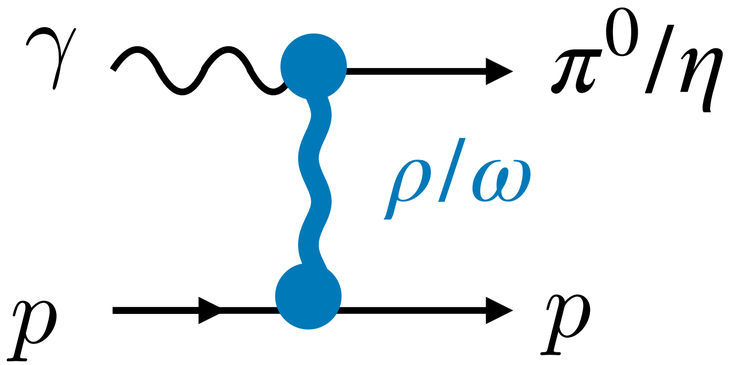

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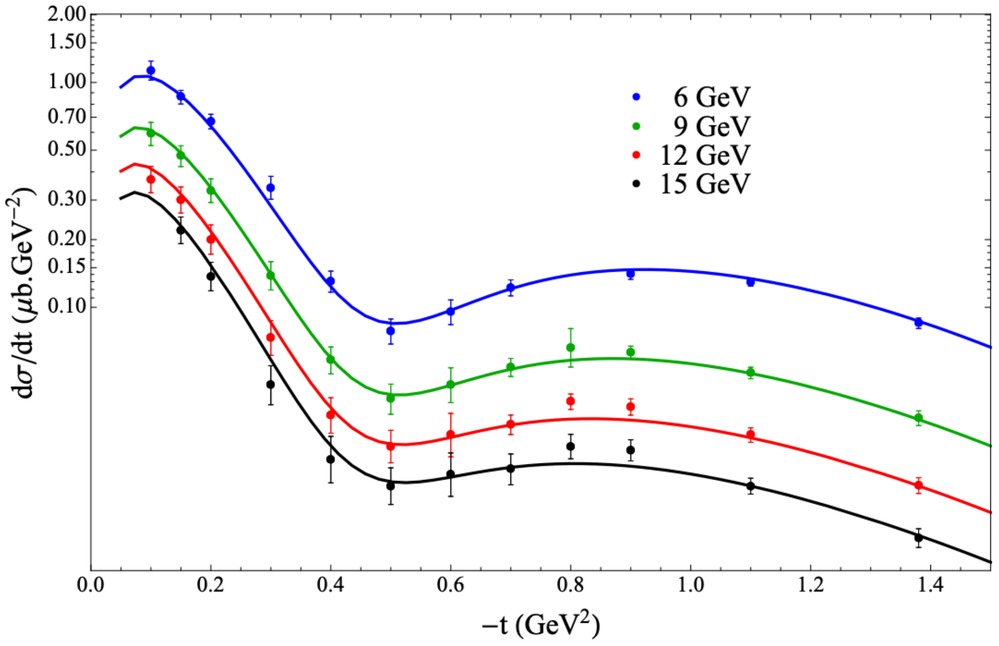
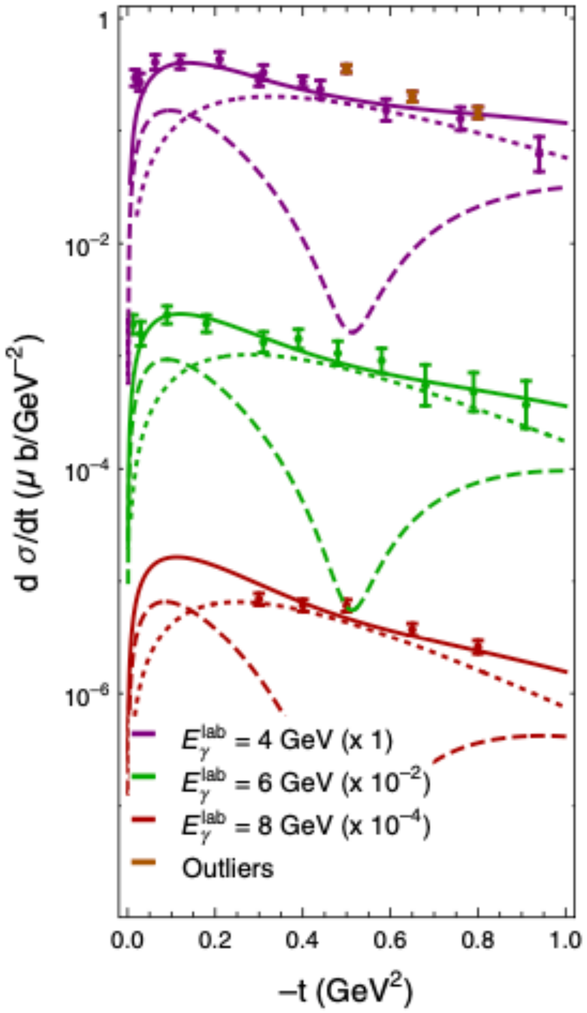


ρ dominates and doesn't dip

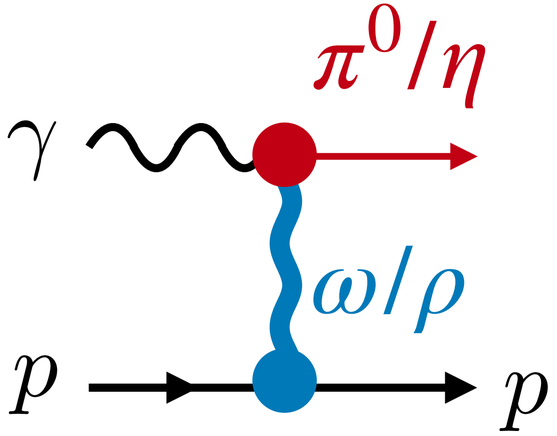


Isovector vs Isoscalar Photoproduction

Dipping cross-section

$$\gamma p \to \pi^0 p :$$

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



Non-dipping cross-section

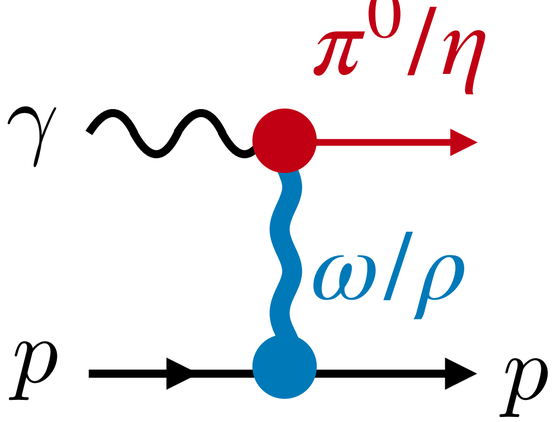
$$\gamma p \to \eta p :$$

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

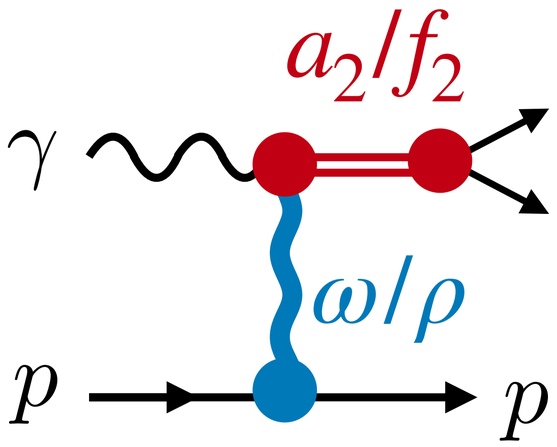
Isovector vs Isoscalar Photoproduction

Dipping cross-section

$$\gamma p \to \pi^0 p : \quad \omega + \frac{1}{3}\rho$$



$$\gamma p \to a_2(1320) p : \quad \omega + \frac{1}{3}\rho$$



Non-dipping cross-section

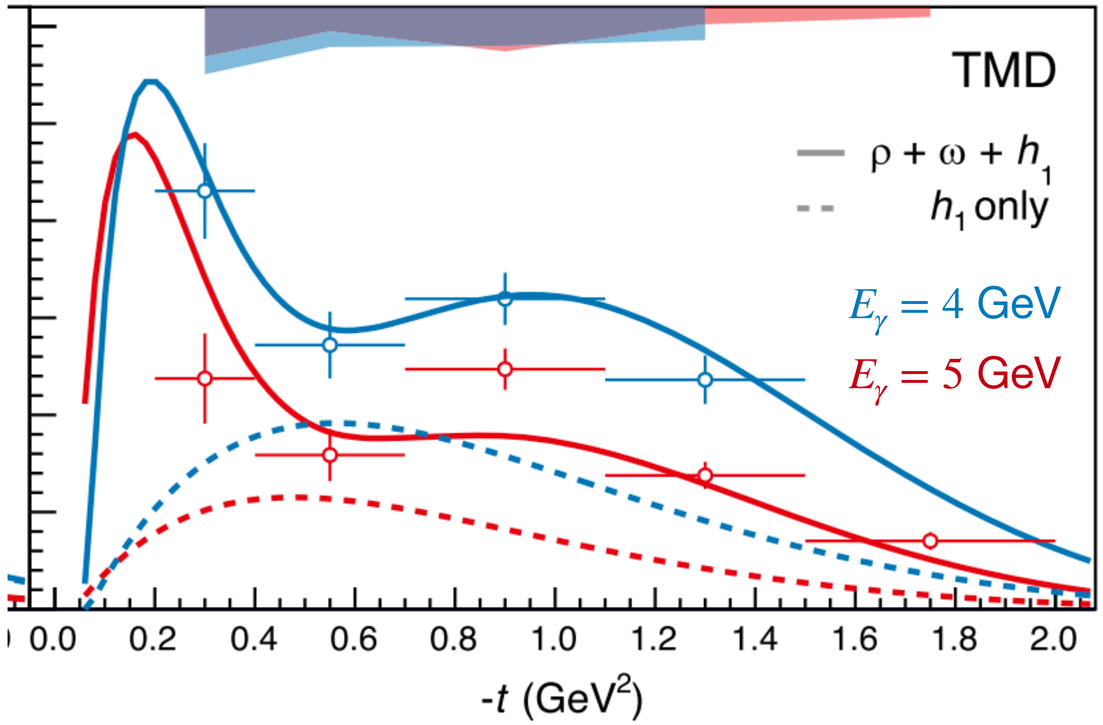
$$\gamma p \to \eta p : \quad \rho + \frac{1}{3}\omega$$

$$\gamma p \to f_2(1270) p : \quad \rho + \frac{1}{3}\omega$$

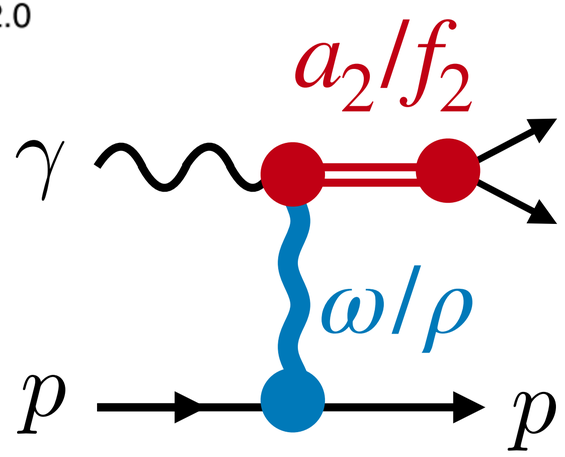
Tensor Meson Photoproduction @CLAS

VM et al (JPAC) PRD102 (2020)

CLAS PRC 102 (2020)



$$\gamma p \to a_2(1320)p : \quad \omega + \frac{1}{3}\rho$$

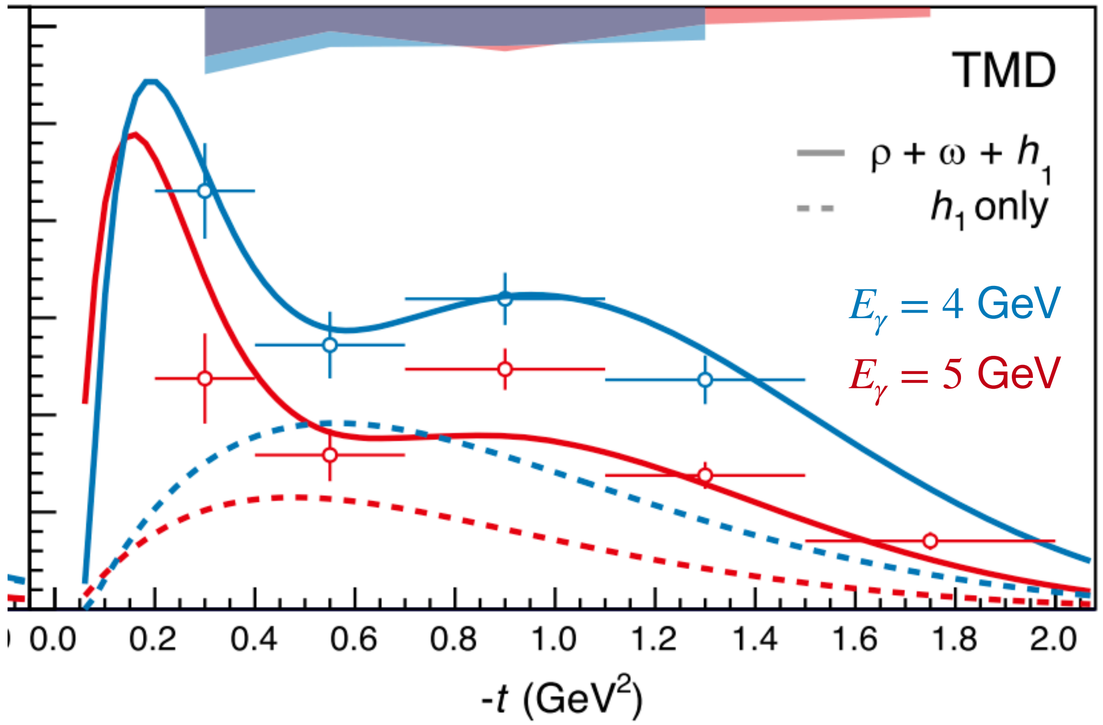


$$\gamma p \to f_2(1270)p : \quad \rho + \frac{1}{3}\omega$$

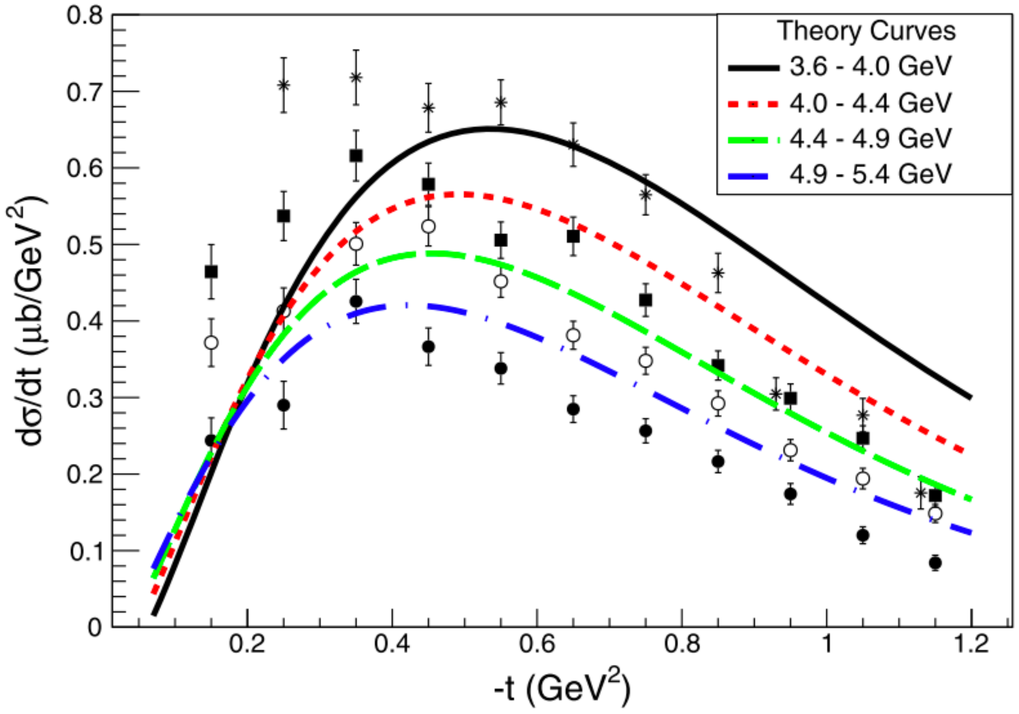
Tensor Meson Photoproduction @CLAS

VM et al (JPAC) PRD102 (2020)

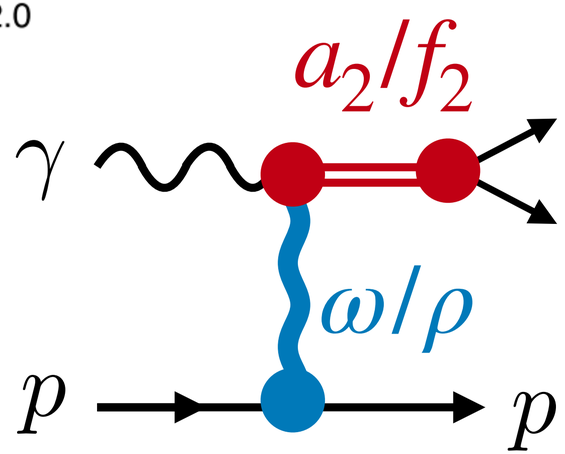
CLAS PRC 102 (2020)



CLAS PRL126 (2021)



$$\gamma p \to a_2(1320)p : \quad \omega + \frac{1}{3}\rho$$

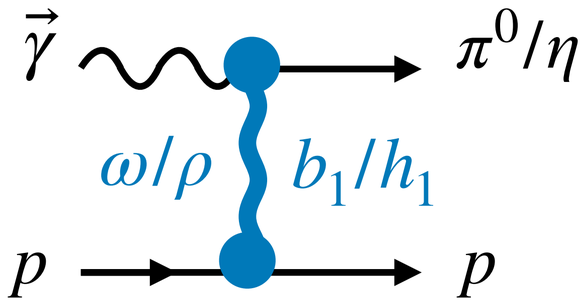


$$\gamma p \to f_2(1270)p : \quad \rho + \frac{1}{3}\omega$$

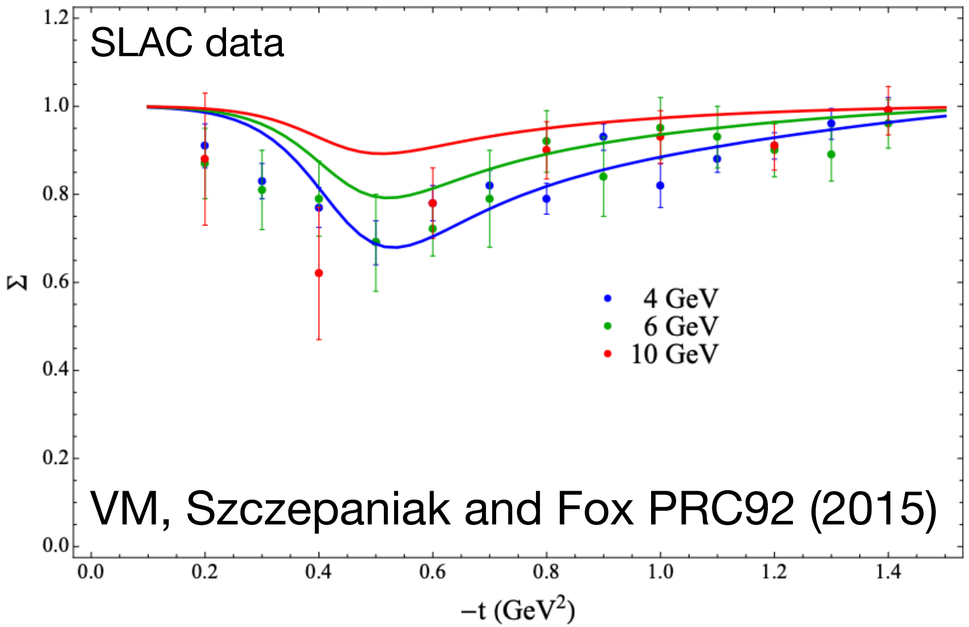
π^0/η Beam Asymmetry

Axial exchange contributions from SLAC beam asymmetry

$$\Sigma = \frac{(\rho + \omega) - (b_1 + h_1)}{(\rho + \omega) + (b_1 + h_1)}$$



Prediction for GlueX



π^0/η Beam Asymmetry

GlueX, VM and J. Nys PRC95 (2017)

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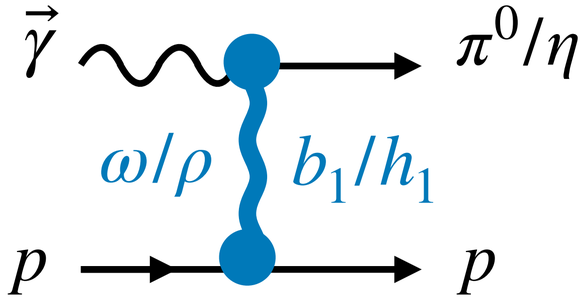

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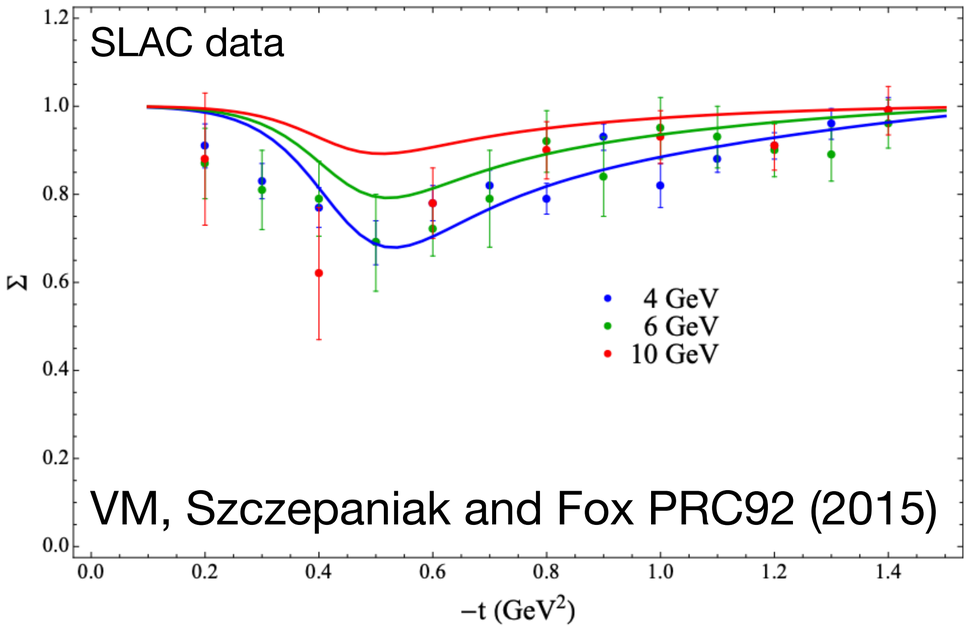
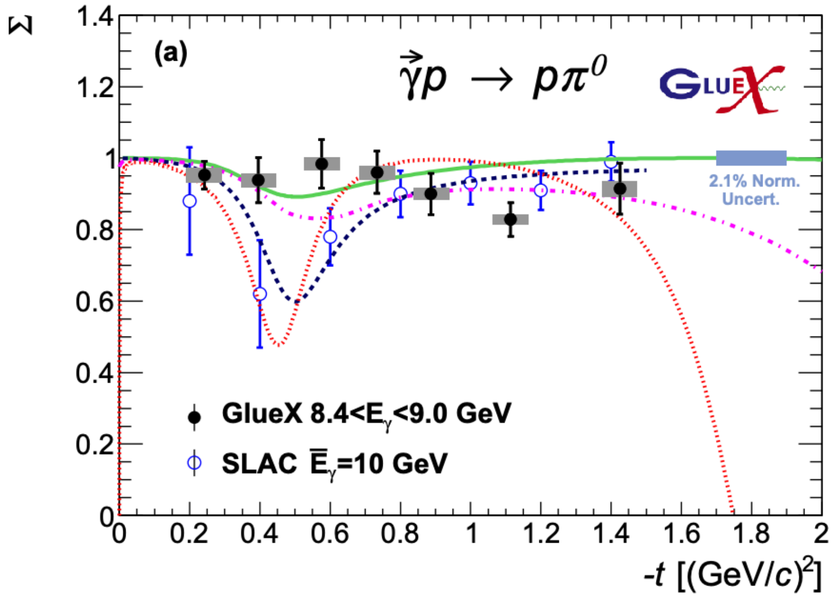
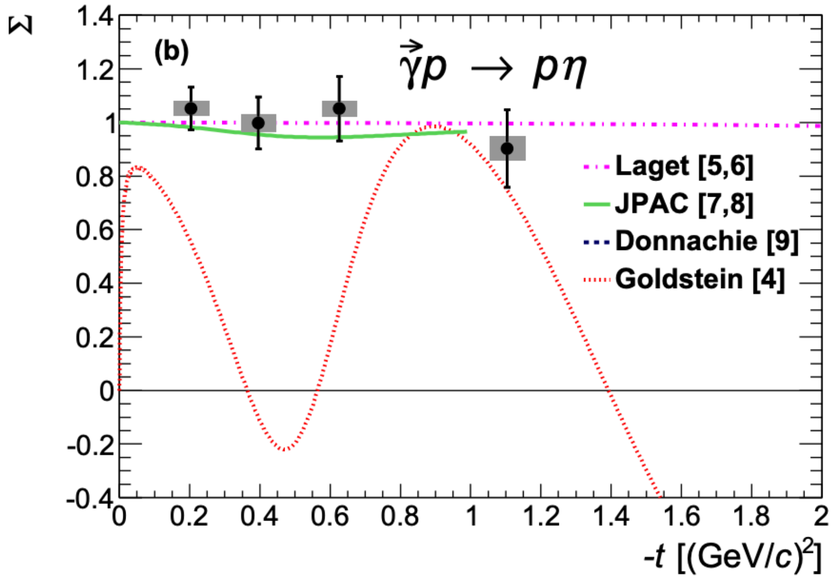




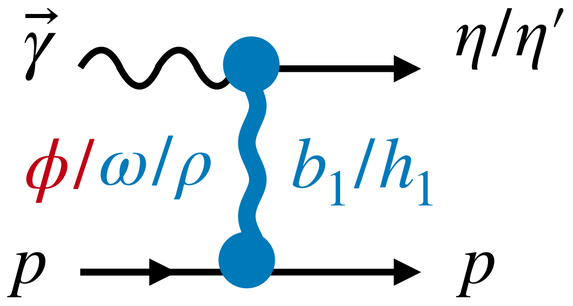


η' Beam Asymmetry

If factorization

If no ϕ exchange

$$\Sigma_{\eta'} = \Sigma_{\eta}$$



η' Beam Asymmetry

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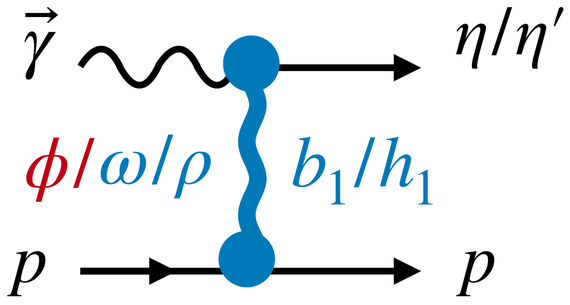
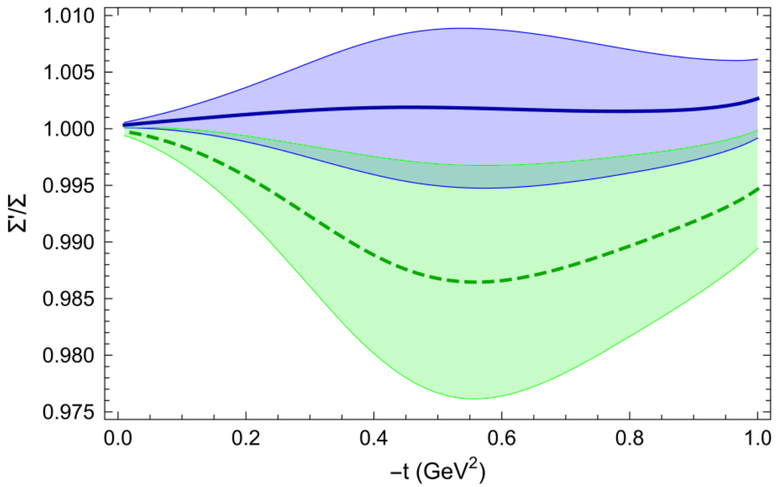
Theoretical estimation of ϕ exchange



VM et al (JPAC) PLB774 (2017)



Very small ϕ exchange

$\Sigma_{\eta'} \neq \Sigma_{\eta}$ implies violation of factorization in η'

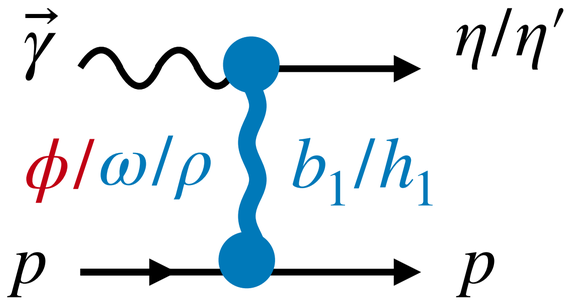
η' Beam Asymmetry

If factorization

If no ϕ exchange

$$\Rightarrow \quad \Sigma_{\eta'} = \Sigma_{\eta}$$

Theoretical estimation of ϕ exchange



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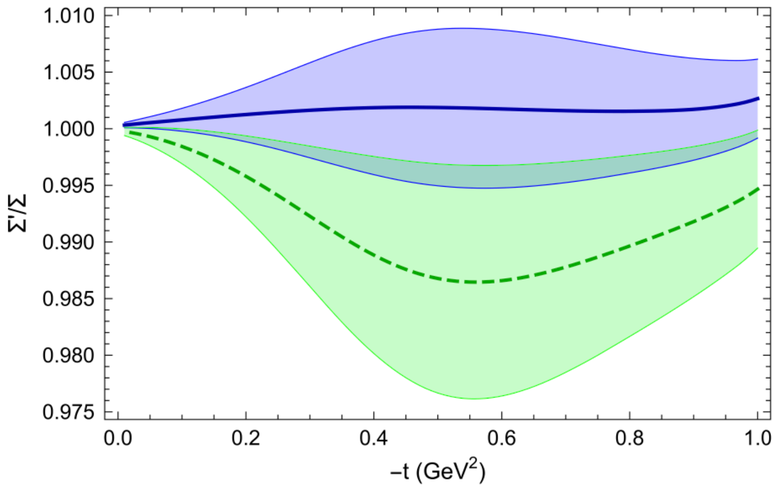

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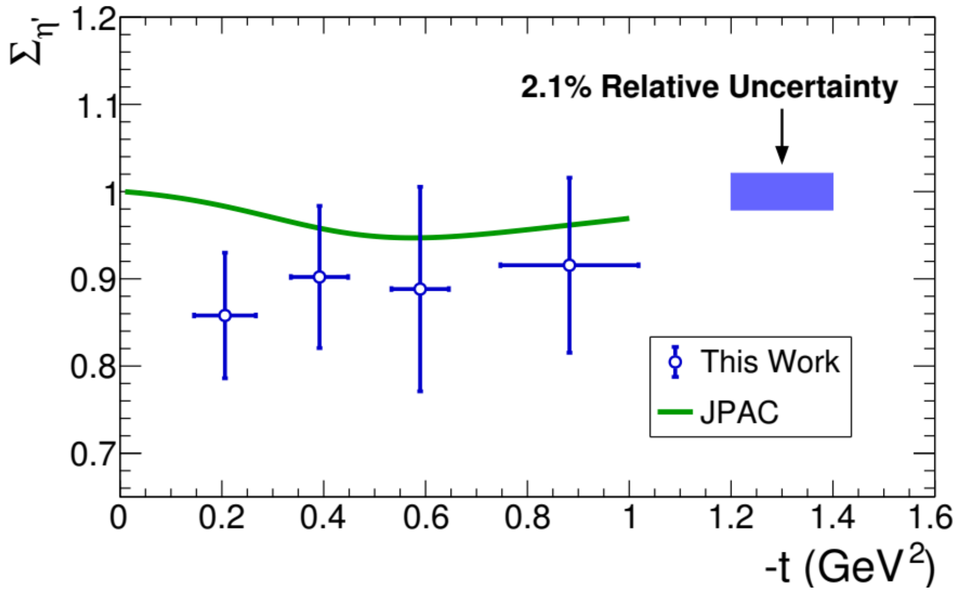
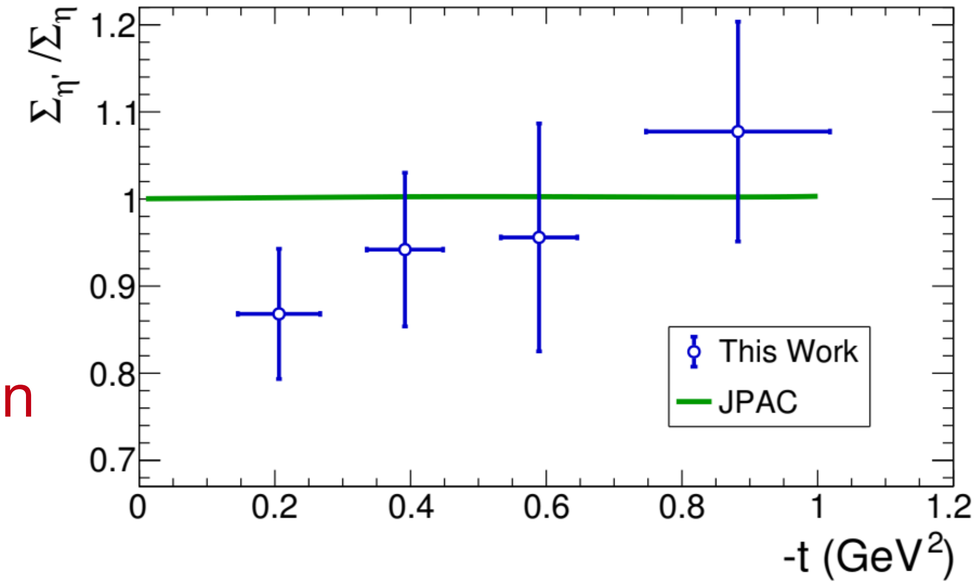
GlueX PRC100 (2019)





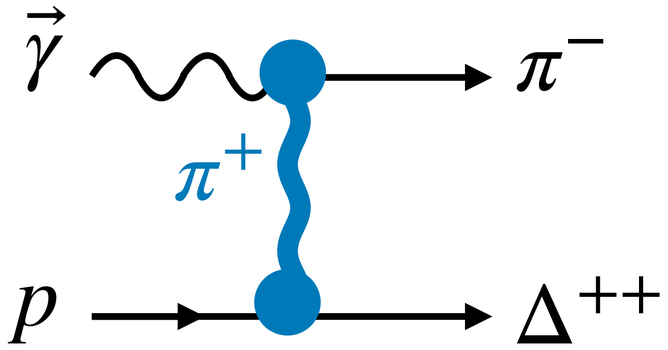
Δ^{++} Photoproduction @GlueX

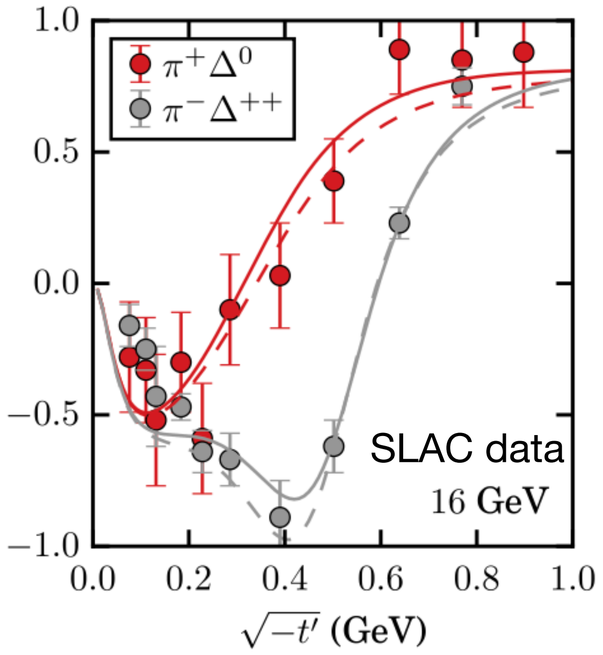
J. Nys et al (JPAC) PLB779 (2018)

π exchange dominates at small $|t|$

Absorption correction of π exchange
included via the Poor man absorption corrections

Natural exchanges ρ and a_2 estimated from SLAC data





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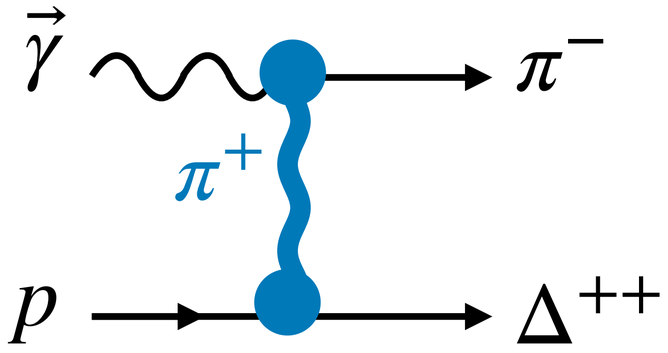
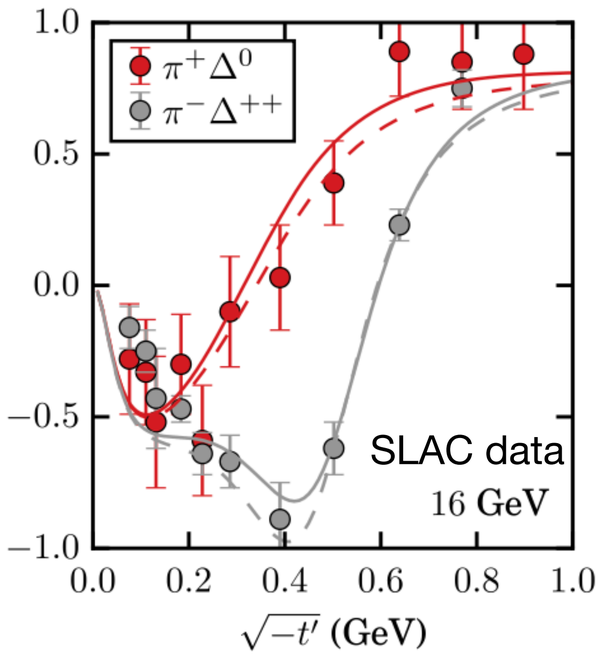
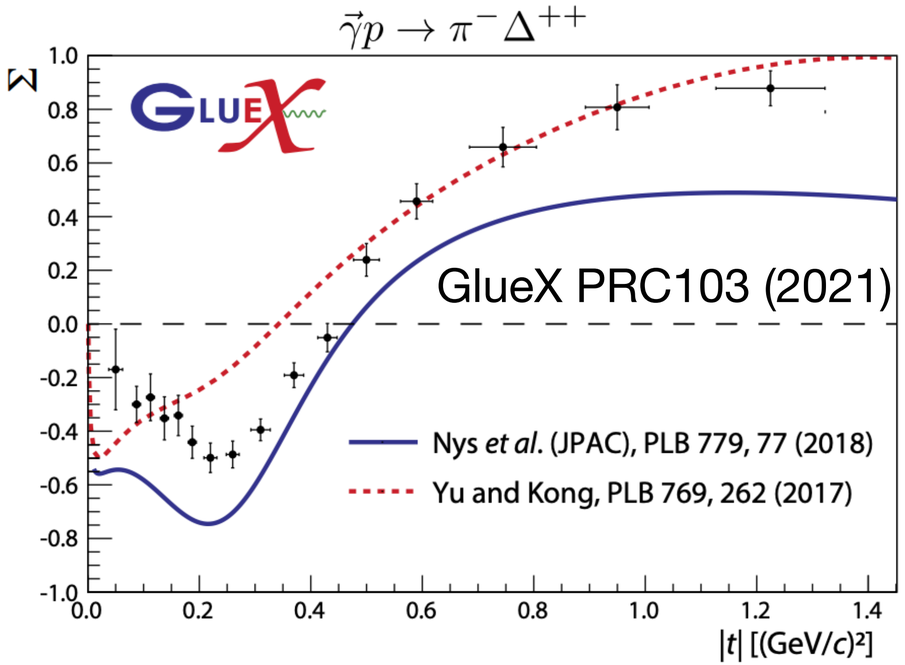




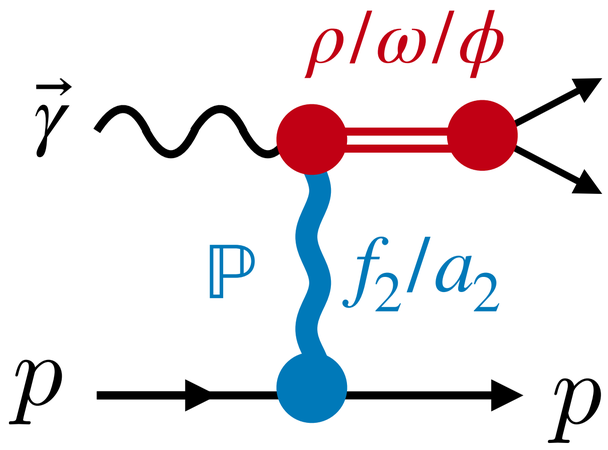


Light Vector Spin Density Matrix Elements

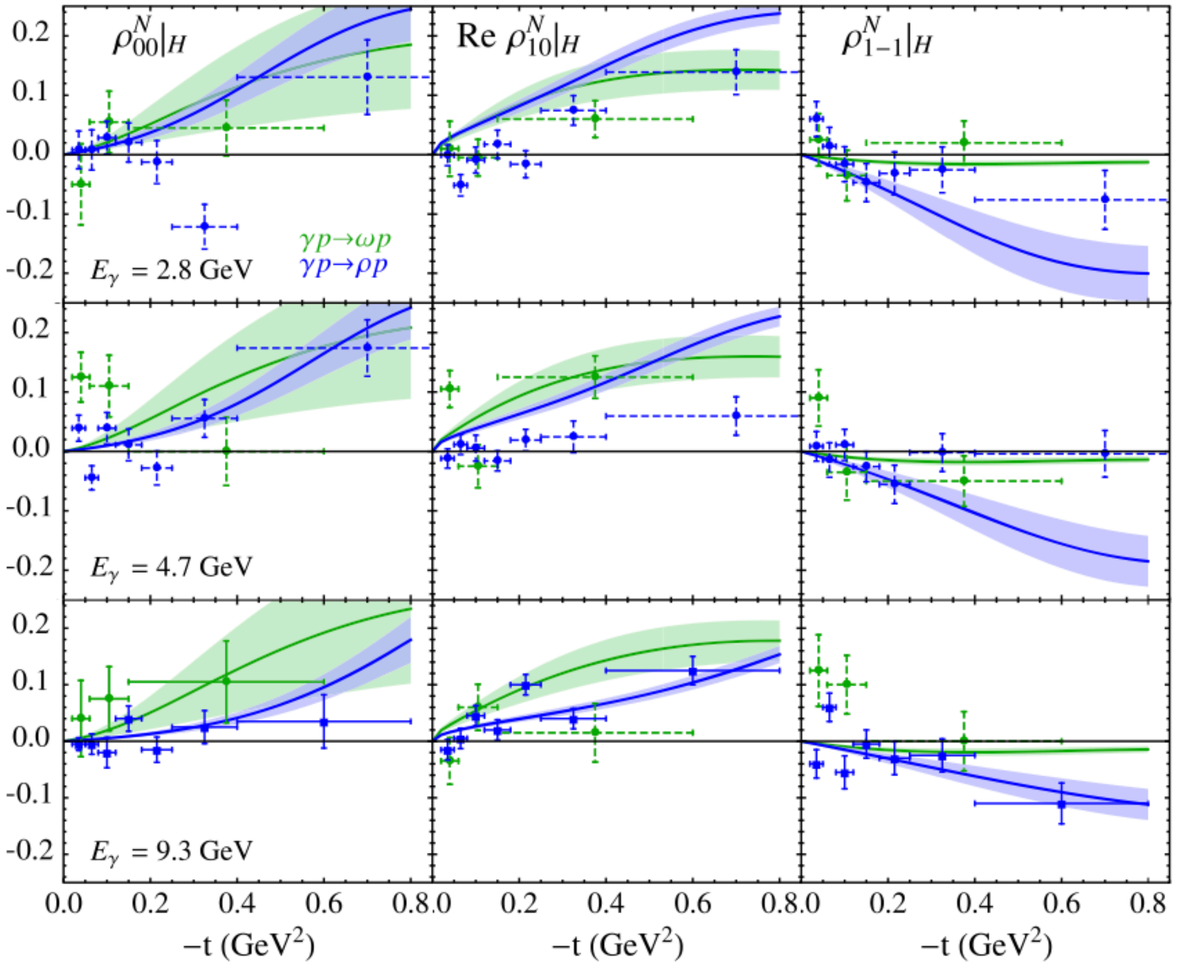
VM et al (JPAC) PRD97 (2018)

SDME extracted from angular dependence provide information about the production

Probe the helicity structure of top couplings $\beta_{\lambda_\gamma,\lambda_V}(t)$



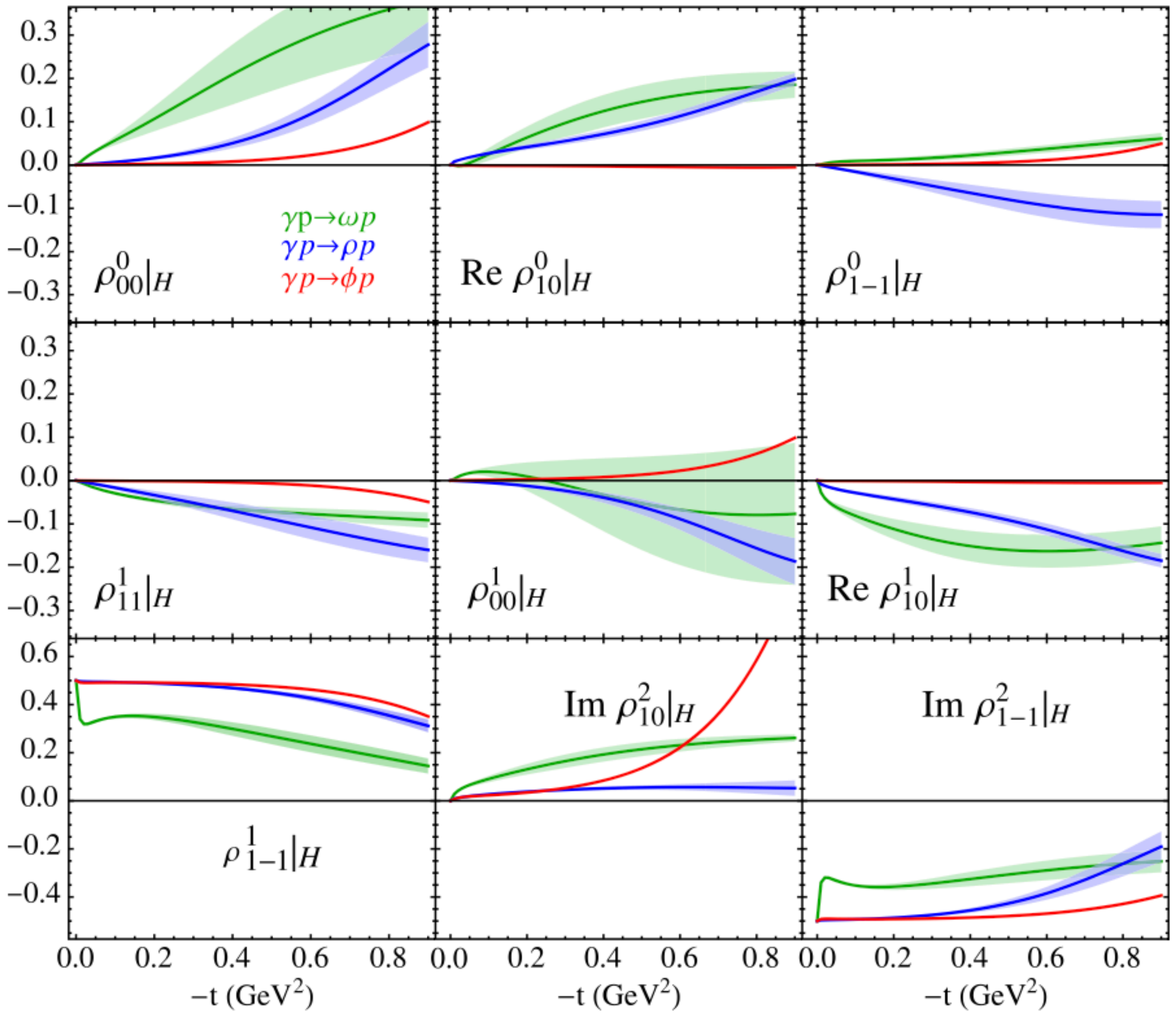
Couplings Extracted from SLAC data



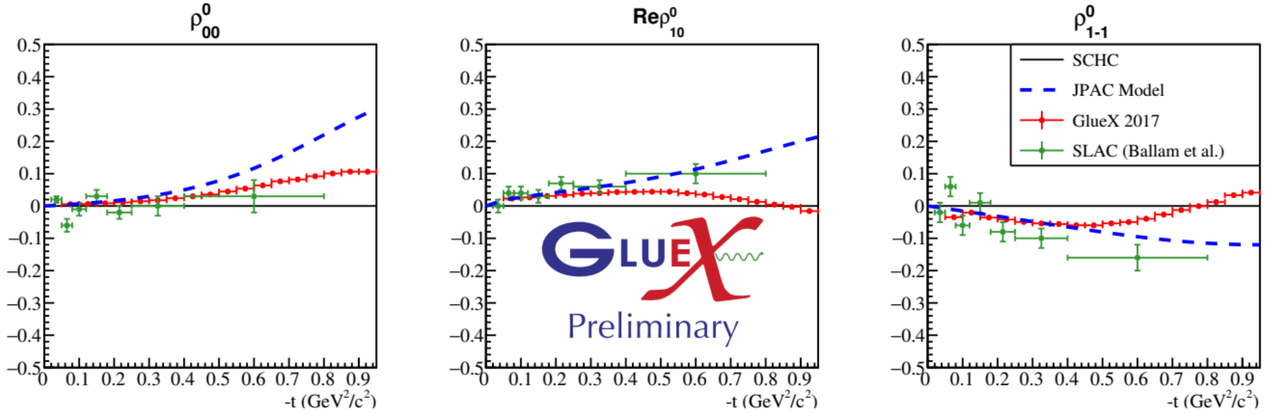
Light Vector Spin Density Matrix Elements

VM et al (JPAC) PRD97 (2018)

Predictions for GlueX (and CLAS)



A. Austregesilo (GlueX) MENU 2019 arXiv:1908.07275



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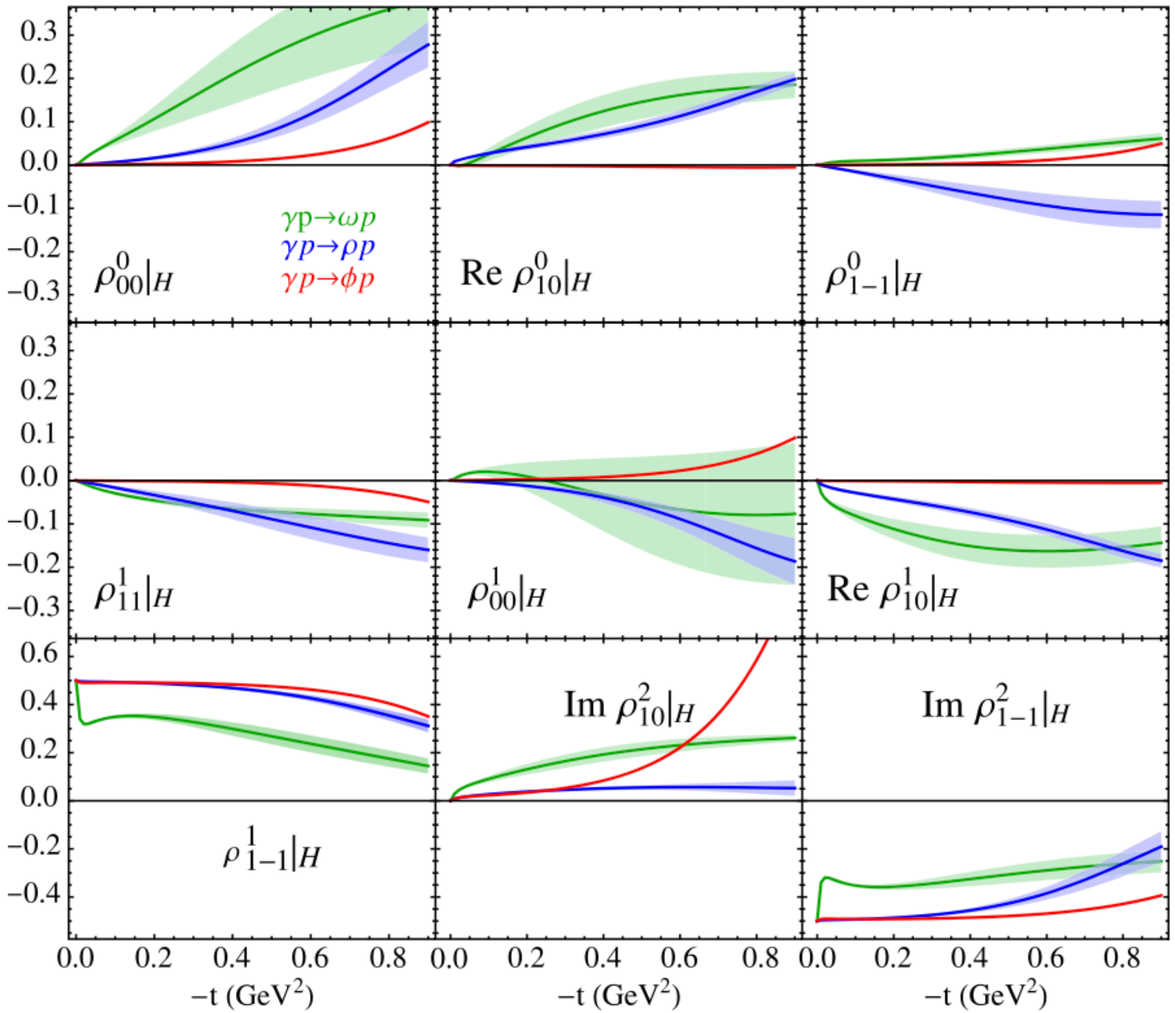

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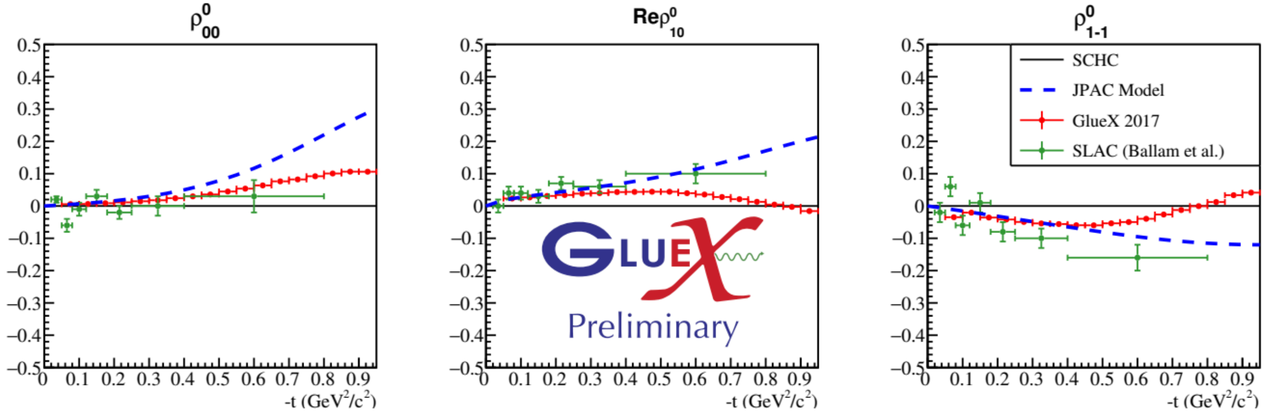
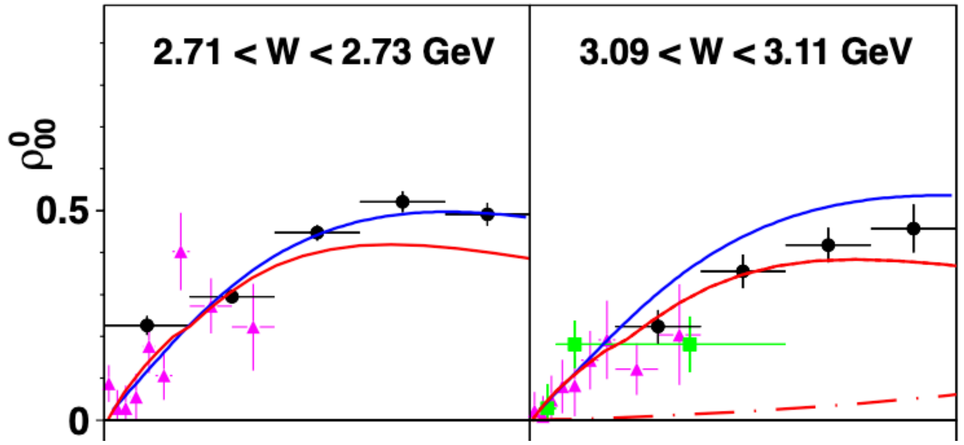
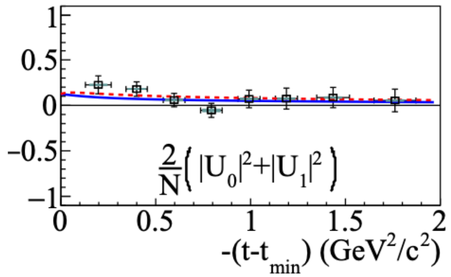


CLAS12 and VM submitted to PRL

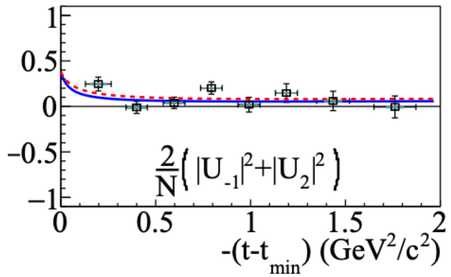


$\Lambda(1520)$ Spin Density Matrix Elements

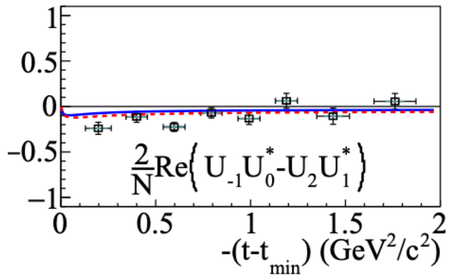
GlueX and VM PRC105 (2022)



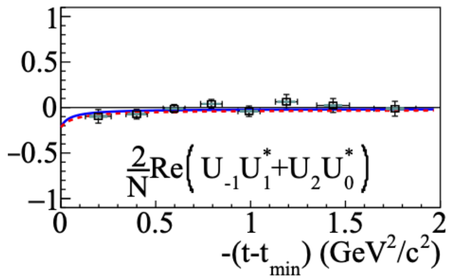
$$\rho^0_{11} - \rho^1_{11} = \frac{2}{\mathcal{N}}\left(|U_0|^2 + |U_1|^2\right)$$



$$\rho^0_{33} - \rho^1_{33} = \frac{2}{\mathcal{N}}\left(|U_{-1}|^2 + |U_2|^2\right)$$

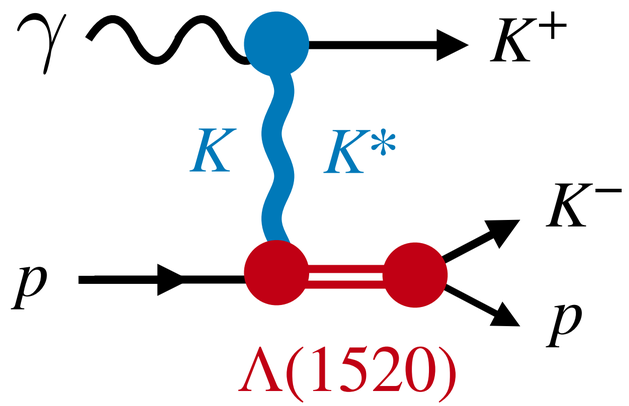


$$\mathrm{Re}\left(\rho^0_{31} - \rho^1_{31}\right) = \frac{2}{\mathcal{N}}\mathrm{Re}\left(U_{-1}U_0^* - U_2U_1^*\right)$$



$$\mathrm{Re}\left(\rho^0_{3-1} - \rho^1_{3-1}\right) = \frac{2}{\mathcal{N}}\mathrm{Re}\left(U_{-1}U_1^* + U_2U_0^*\right)$$

Model from Yu and Kong PRC96 (2017)



Separation between
natural $K*$ and unnatural K exchanges

Good agreement with one Kaon exchange

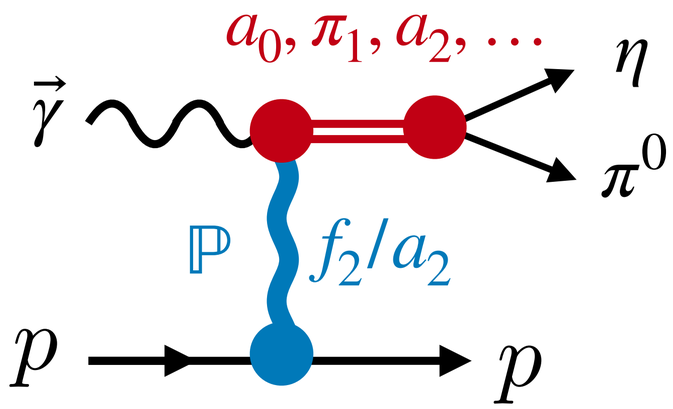
Two Pseudoscalar Photoproduction

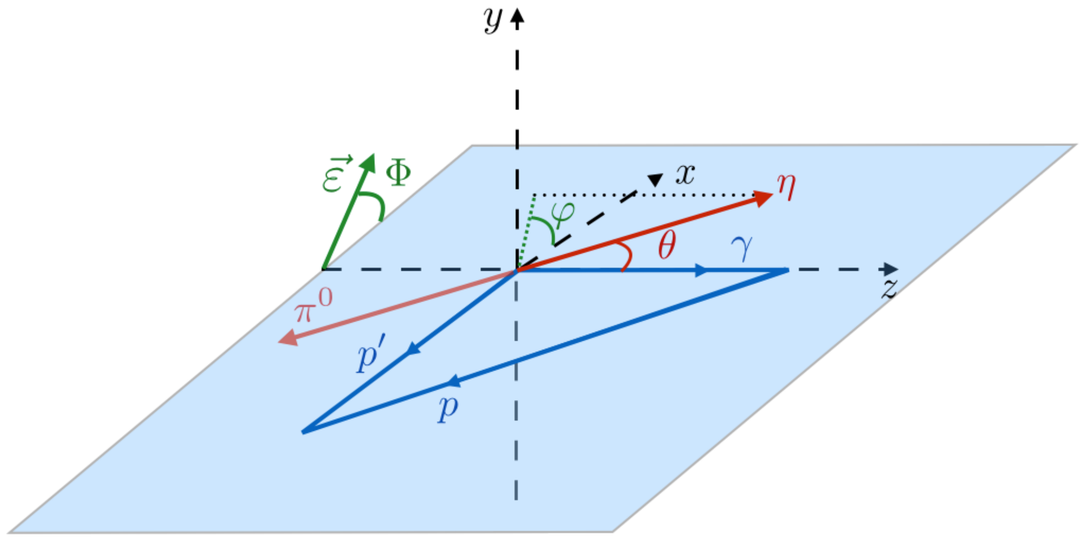
VM et al PRD100 (2019) 054017

Angular decomposition of the intensity leads to moments

$$I(\Omega, \Phi) = I^0(\Omega) - P_\gamma I^1(\Omega)\cos 2\Phi - P_\gamma I^2(\Omega)\sin 2\Phi$$

$$H^0(LM) = \frac{1}{2\pi}\int I^0(\Omega)\, d^L_{M,0}(\theta)\, \cos(M\phi)\, d\Omega$$





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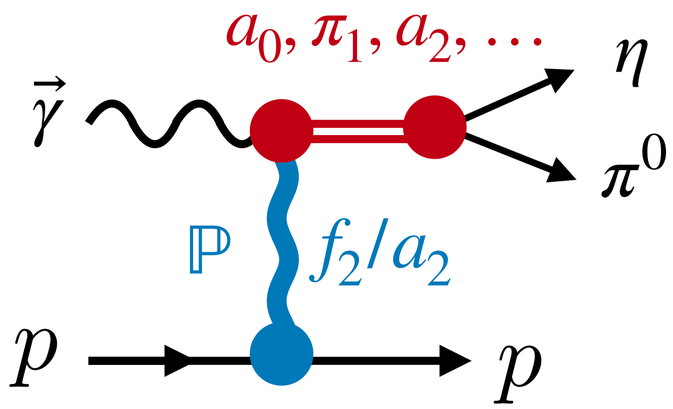
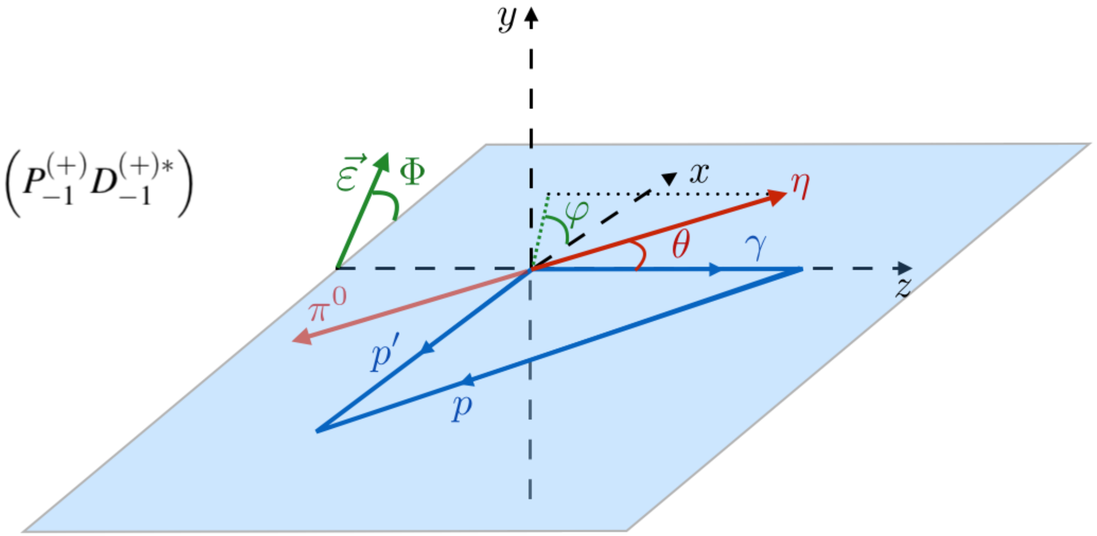


Moments are related to partial waves

$$^{(+)}H^0(10) = \frac{4}{\sqrt{3}}\mathrm{Re}\left(S_0^{(+)}P_0^{(+)*}\right) + \frac{8}{\sqrt{15}}\mathrm{Re}\left(P_0^{(+)}D_0^{(+)*}\right) + \frac{4}{\sqrt{5}}\mathrm{Re}\left(P_1^{(+)}D_1^{(+)*}\right) + \frac{4}{\sqrt{5}}\mathrm{Re}\left(P_{-1}^{(+)}D_{-1}^{(+)*}\right)$$



Formalisms currently use by Gluex and CLAS in the two mesons final states:

$$\pi^0\pi^0, \eta\eta, \pi^0\eta, \pi^0\eta', \pi^-\eta$$

JPAC publications on JLab physics (in this talk)

Single Meson Photoproduction:

$\vec{\gamma}p \to \pi N$ VM et al **PRD92 074013 (2015)**
VM et al **PRD98 014041 (2018)**

$\vec{\gamma}p \to \eta p$ Nys et al **PRD95 034014 (2017)**
VM et al **EPL122 41001 (2018)**

$\vec{\gamma}p \to \eta' p$ VM et al **PLB774 362 (2017)**

$\vec{\gamma}p \to \pi\Delta$ Nys et al **PLB779 77 (2018)**

Vector and Tenson Meson Photoproduction:

$\vec{\gamma}p \to (\rho^0, \omega, \phi)p$ VM et al **PRD97 094003 (2018)**

$\vec{\gamma}p \to (f_2, a_2^0)p$ VM et al **PRD102 014003 (2020)**

Double Mesons Photoproduction:

$\vec{\gamma}p \to \eta\pi p$ VM et al **PRD100 054017 (2019)**

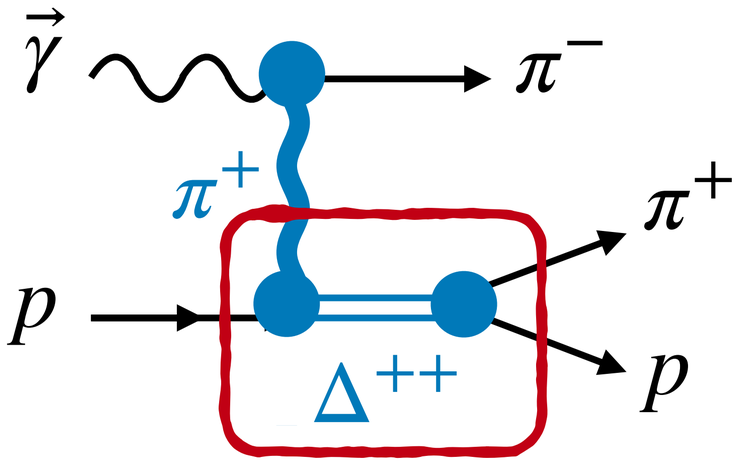
2 publications with GlueX and 3 publications with CLAS

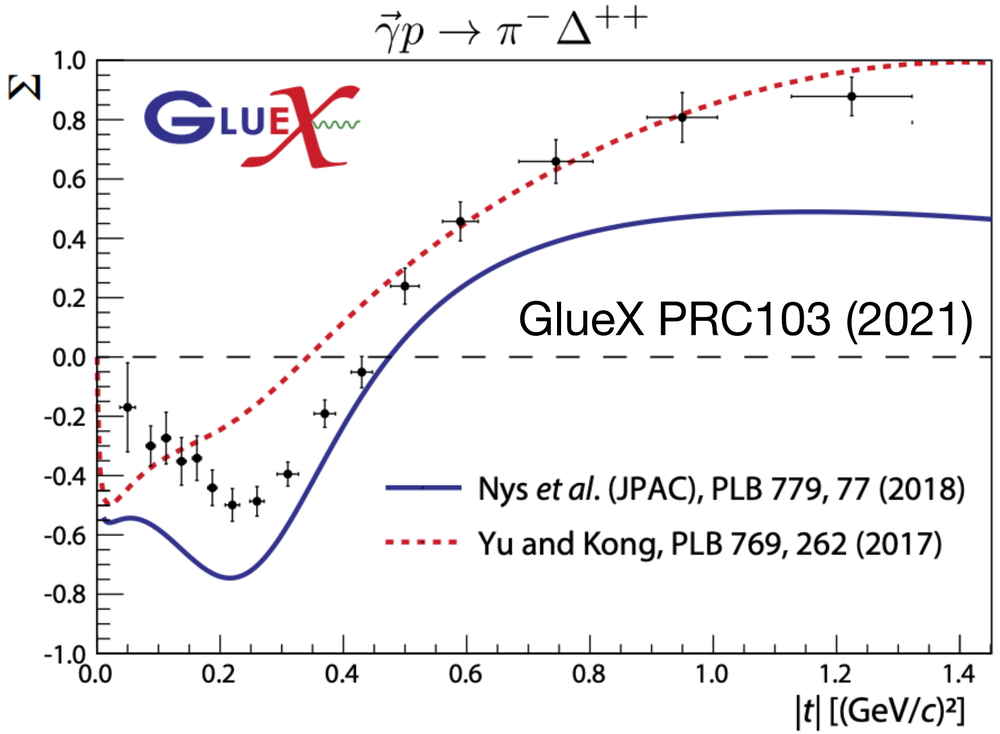
Simulations and codes available: http://www.jpac-physics.org/

Ongoing and future projects

Δ^{++} Photoproduction @GlueX

Inclusion of full $\pi^+ p$ elastic scattering



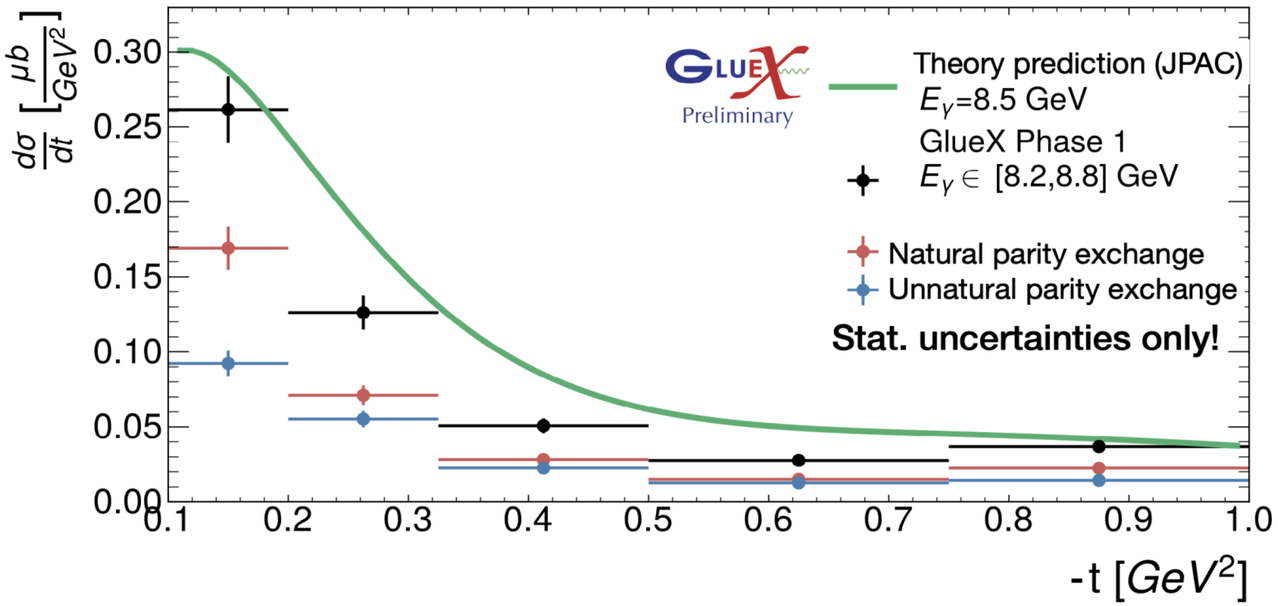


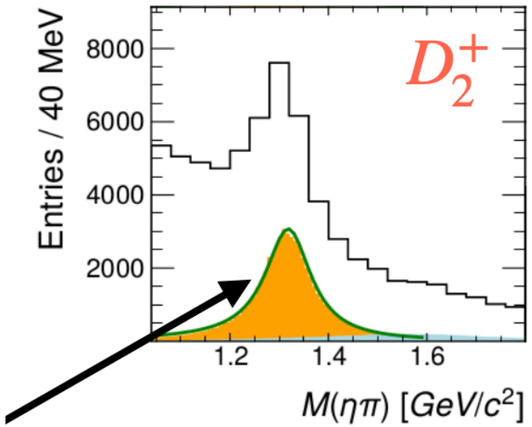
Improved description of the complete reaction

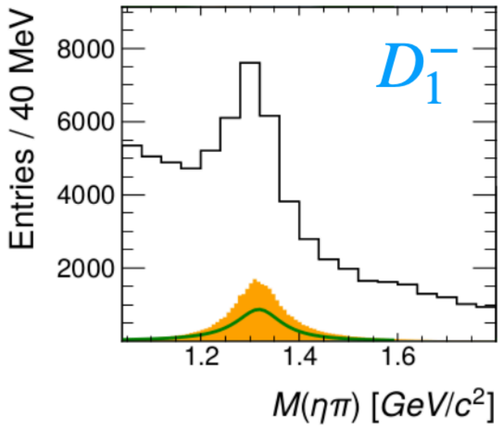
$$\vec{\gamma}p \to \pi^+\pi^- p$$

Future plan: $\vec{\gamma}p \to \pi^-\eta\Delta^{++}, \quad \Delta^{++} \to \pi^+ p$

$a_2(1320)$ Photoproduction @GlueX

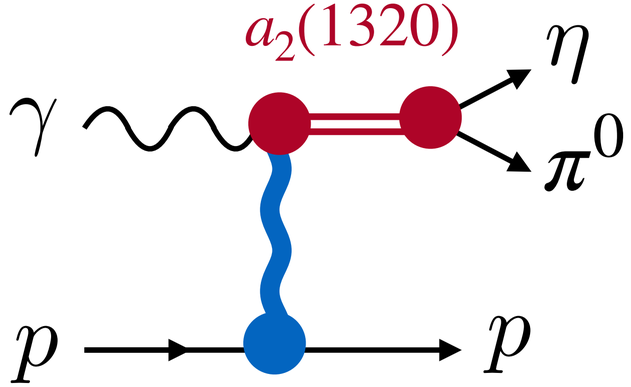






JPAC model for tensor photoproduction

Strong $a_2(1320)$ signal in $\pi\eta$

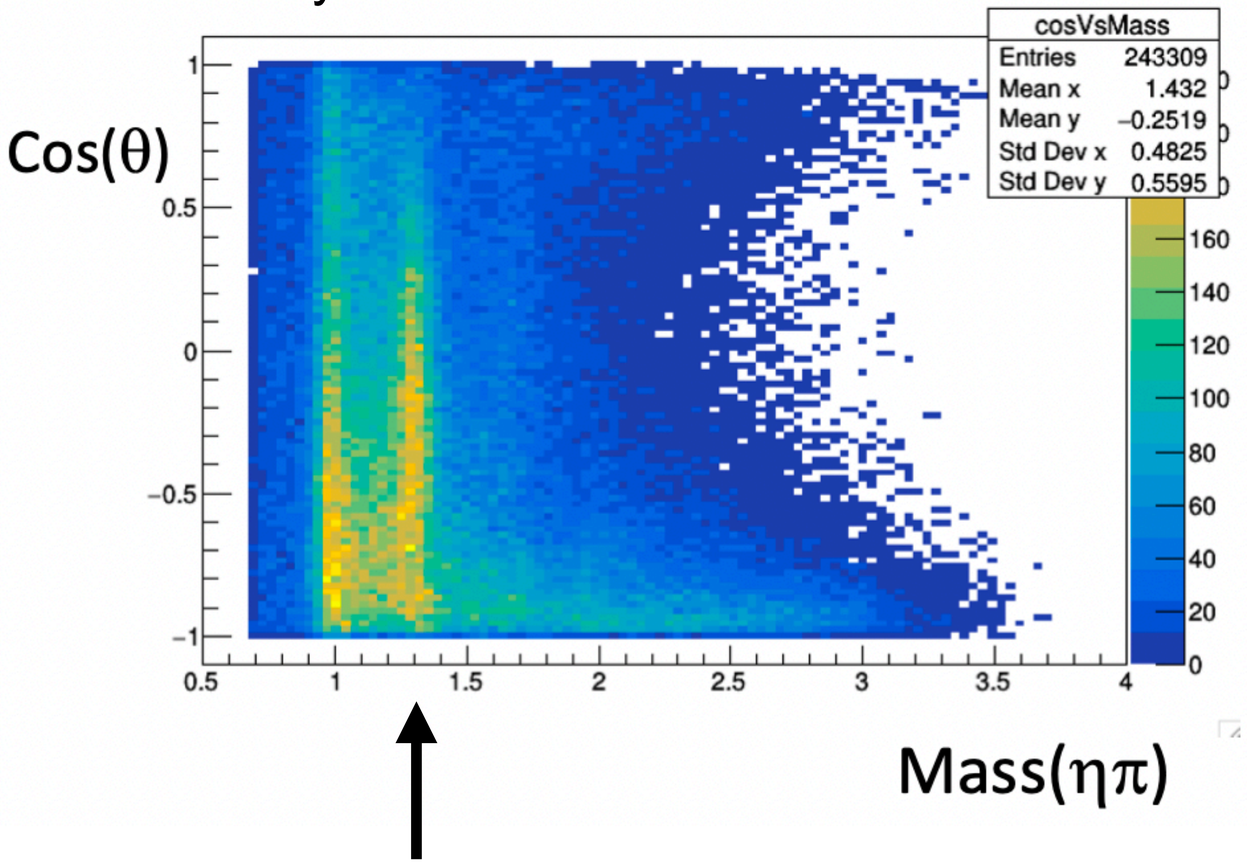


Extraction of the cross-section

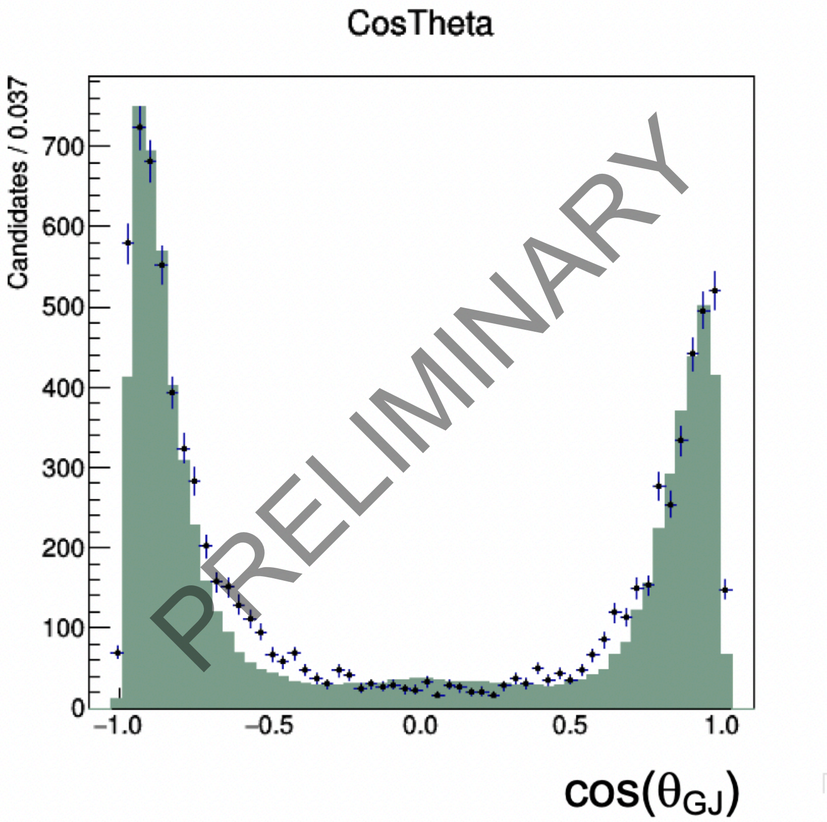
Extraction of all D-waves components

Double Regge $\eta\pi^0$ Photoproduction @GlueX

Baryons have been ‘cut out’



$a_2(1320)$



Double regge with Uniform background

Conclusions

JPAC developed models based on Regge theory for meson(s) photoproduction

Analyses of pseudoscalar, vector and tensor mesons revealed:

Dominance of natural exchange + Agreement with factorized models

Except in π exchange reaction ($\gamma p \to \pi^- \Delta^{++}$) But π exchange under control

JPAC developed the formalisms to extract meaningful observables in meson(s) photoproduction

Fruitful interaction between JPAC and JLab exp. collaboration

Predictions available online: http://www.jpac-physics.org/

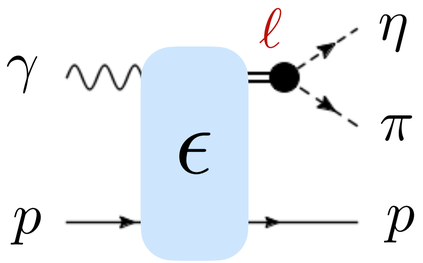
Backup slides

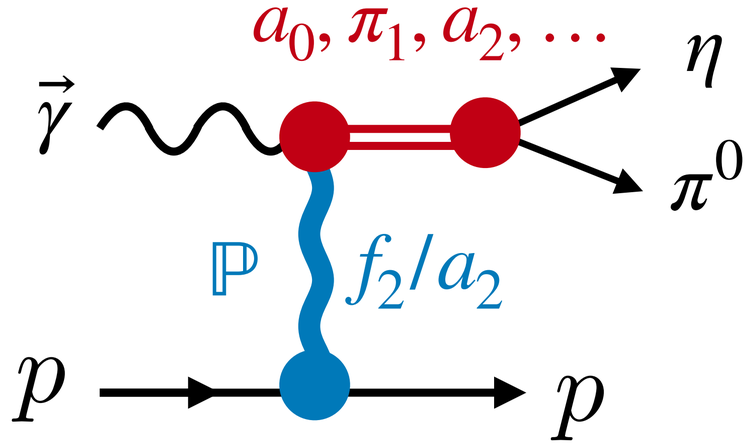
Two Pseudoscalar Photoproduction

VM et al PRD100 (2019) 054017

$$\Sigma_{\mathcal{D}} = \frac{1}{P_\gamma} \frac{\int_{\mathcal{D}} I^{\parallel}(\Omega) - I^{\perp}(\Omega) \mathrm{d}\Omega}{\int_{\mathcal{D}} I^{\parallel}(\Omega) + I^{\perp}(\Omega) \mathrm{d}\Omega}$$

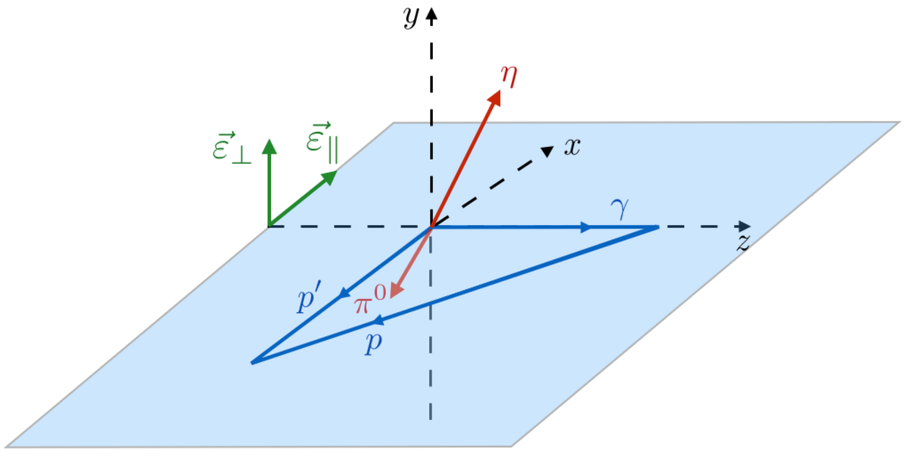
amplitude:
production × decay





Beam asymmetry sensitive to reflection through the reaction plane

use reflection operator = parity followed by 180° rotation around Y-axis

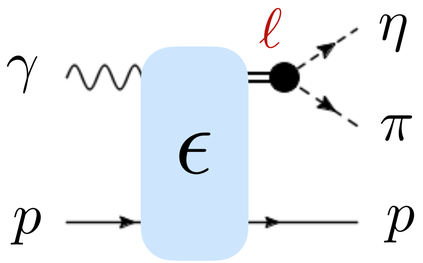


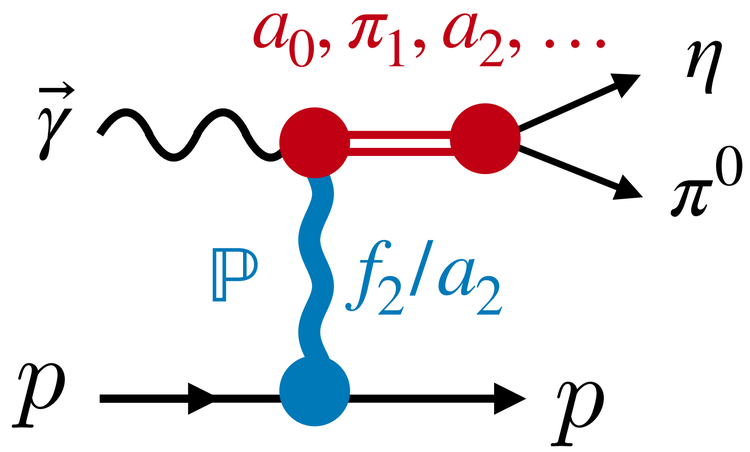
Two Pseudoscalar Photoproduction

VM et al PRD100 (2019) 054017

$$\Sigma_y = \frac{1}{P_\gamma} \frac{I^{\parallel}(\Omega_y) - I^{\perp}(\Omega_y)}{I^{\parallel}(\Omega_y) + I^{\perp}(\Omega_y)}$$

amplitude:
production × decay





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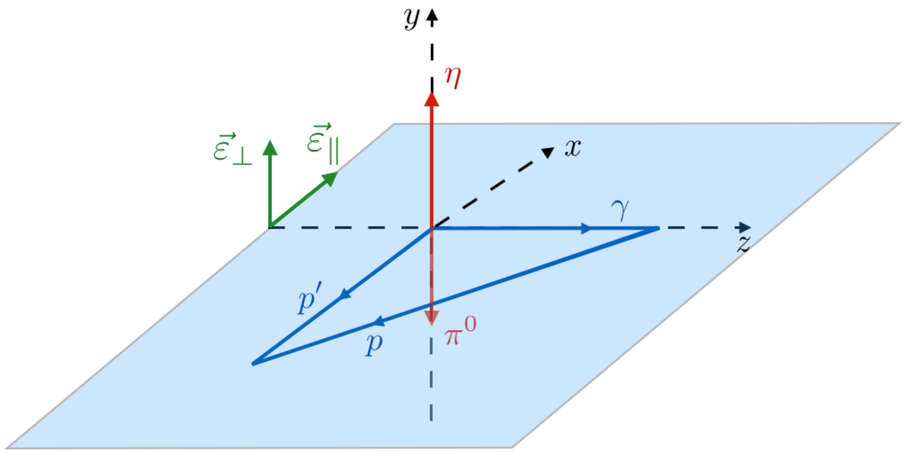

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VM et al PRD100 (2019) 054017

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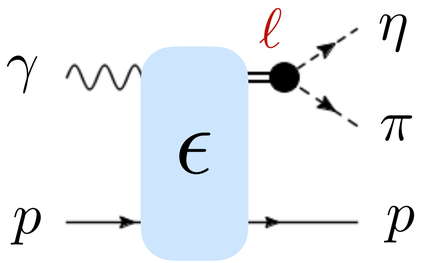
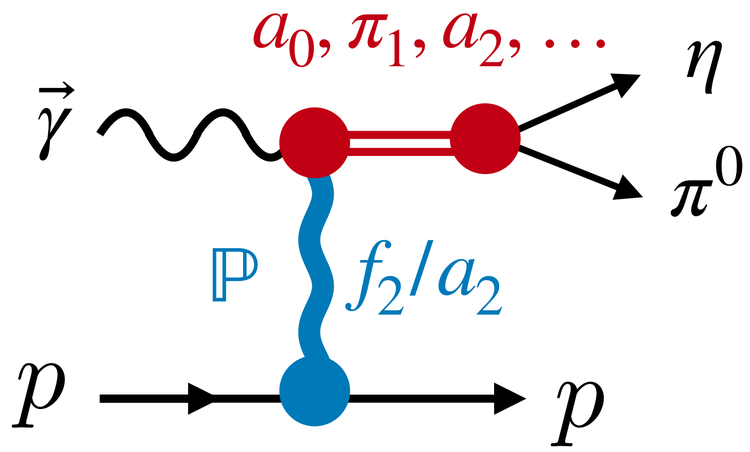


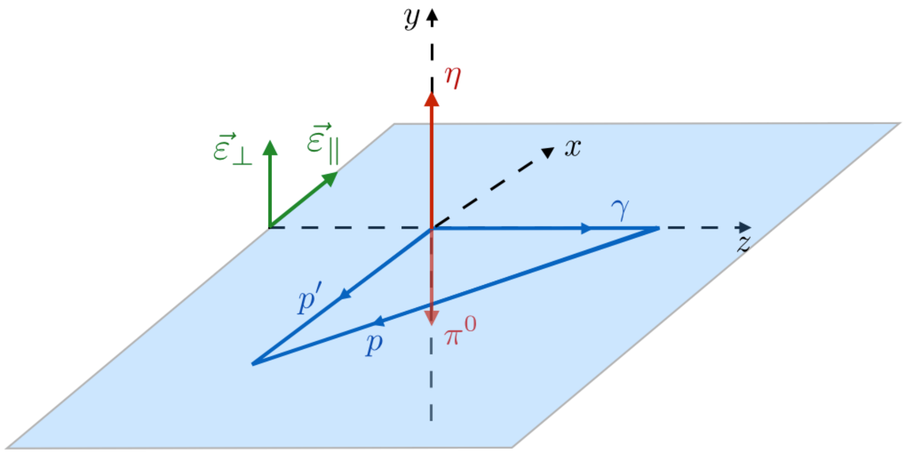


Beam asymmetry sensitive to reflection through the reaction plane

use reflection operator = parity followed by 180° rotation around Y-axis

$$[\ell]_m^{(\epsilon)} \longrightarrow \Sigma_y = \epsilon(-1)^\ell$$

Odd waves change sign!!!



Two Pseudoscalar Photoproduction

VM et al PRD100 (2019) 054017

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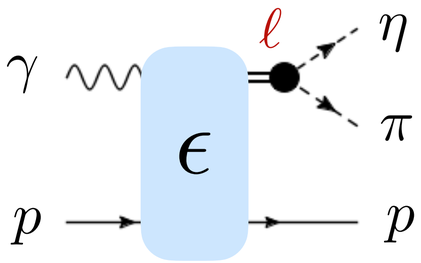
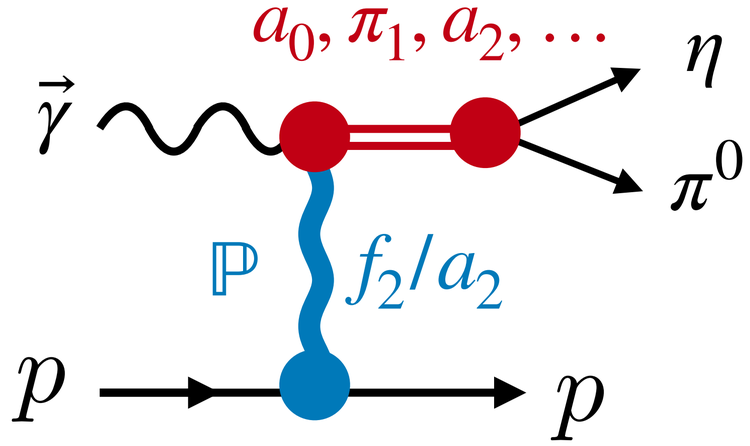




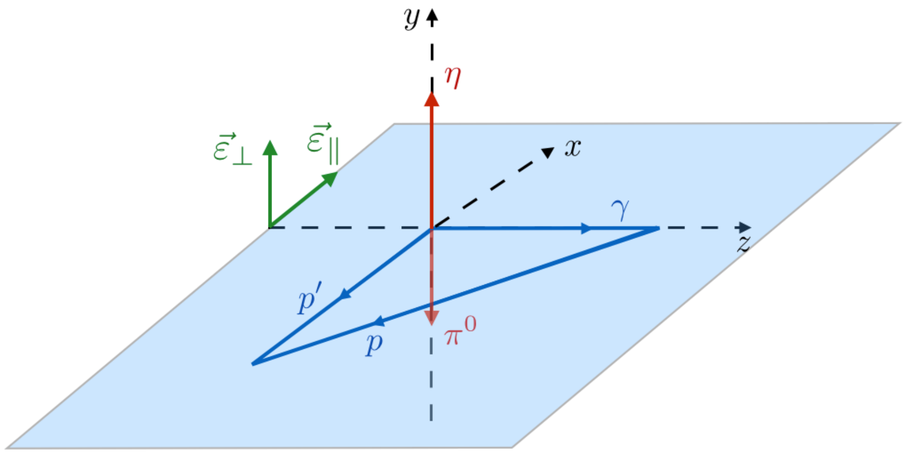
Beam asymmetry sensitive to reflection through the reaction plane

use reflection operator = parity followed by 180° rotation around Y-axis

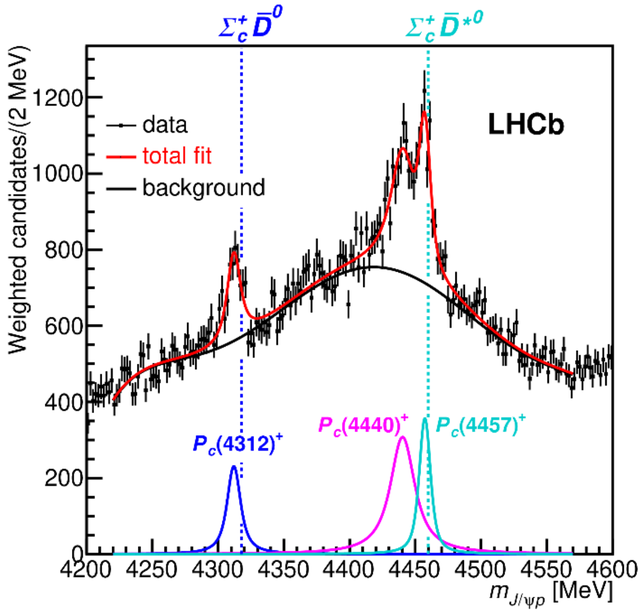
$$[\ell]_m^{(\epsilon)} \longrightarrow \Sigma_y = \epsilon(-1)^\ell$$

Odd waves change sign!!!

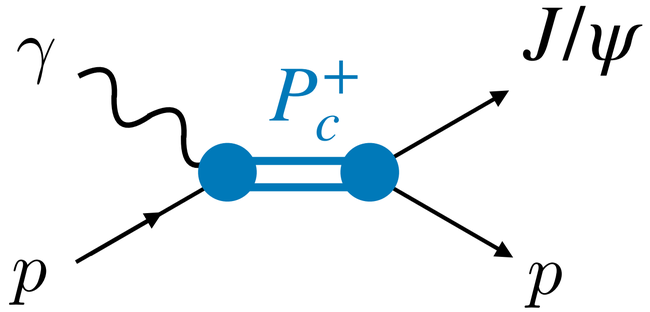
For $\pi^0\pi^0, \eta\eta$ Only even waves $\longrightarrow$ $\Sigma_y = \epsilon$



Direct production of P_c^+?



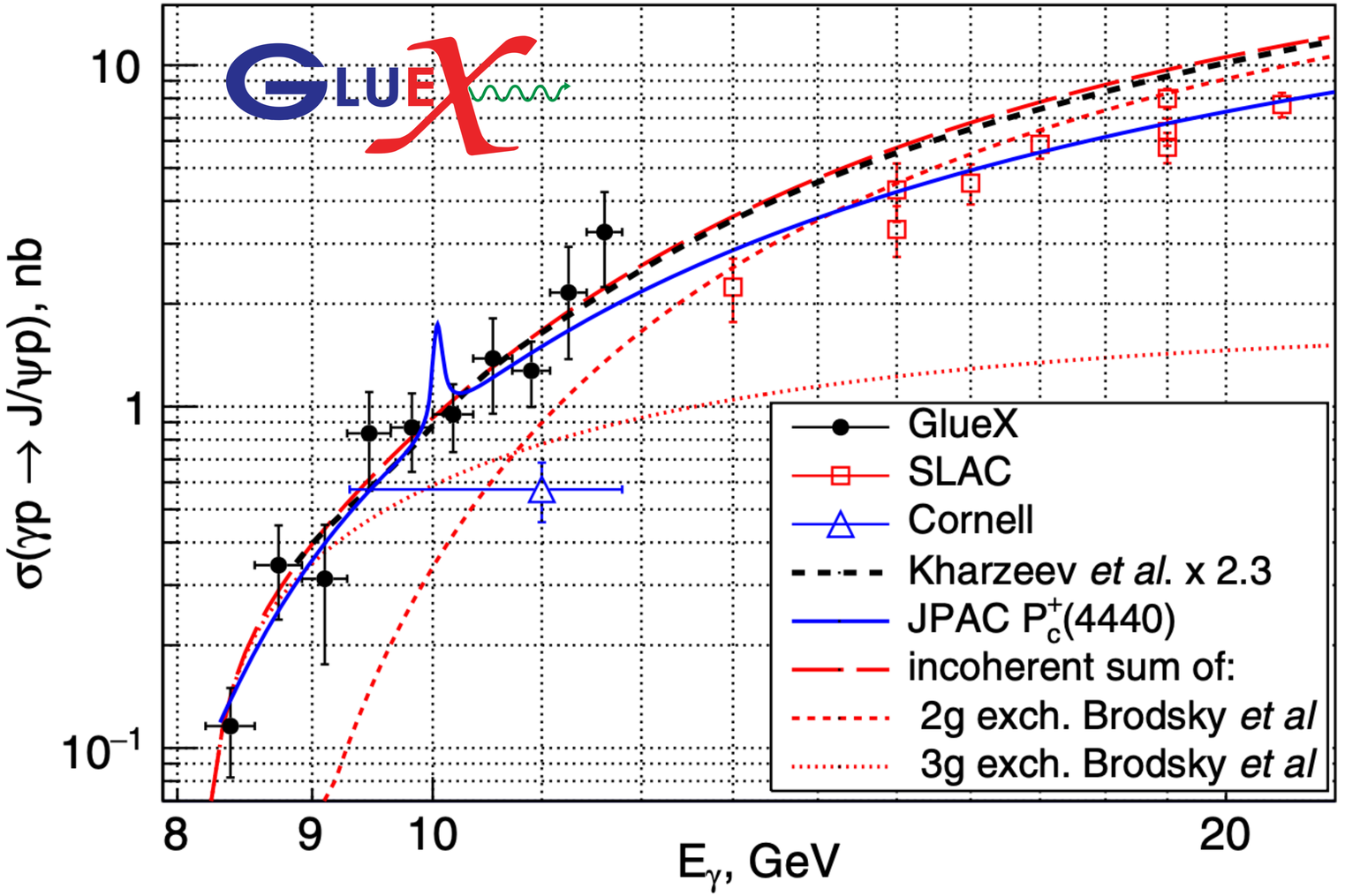
"direct" Photo-production of P_c^+



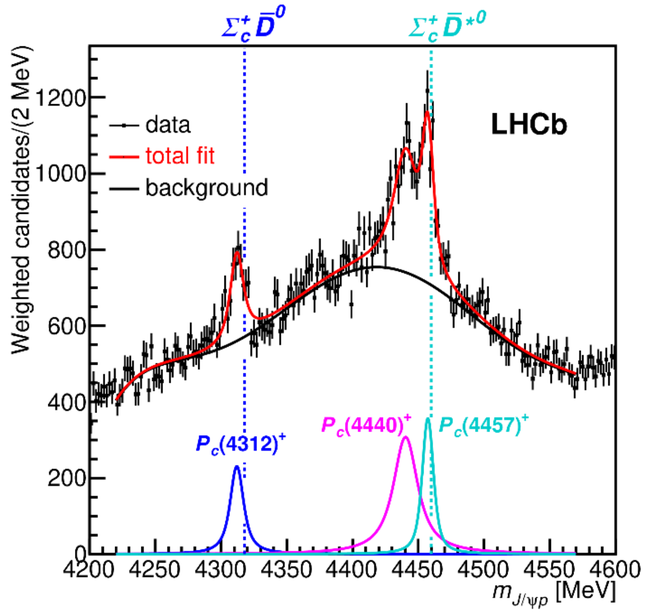
Estimation of the couplings with VMD

Data GlueX, PRL23 (2019) 072001

Model Hiller-Blin et al (JPAC), PRD94 (2016) 034002



Direct production of P_c^+?



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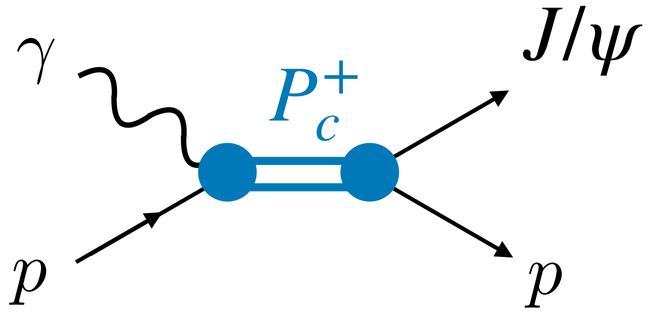

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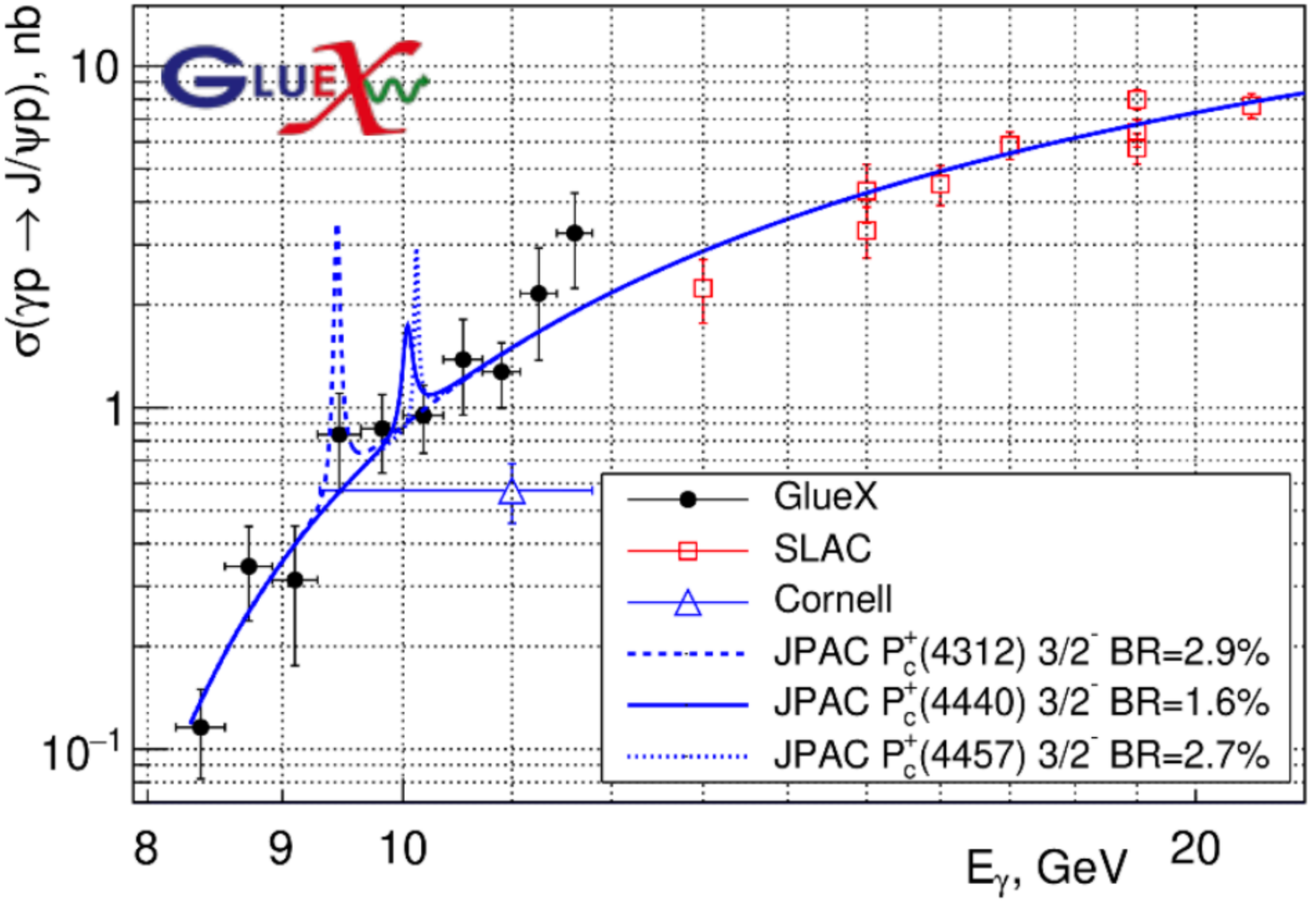
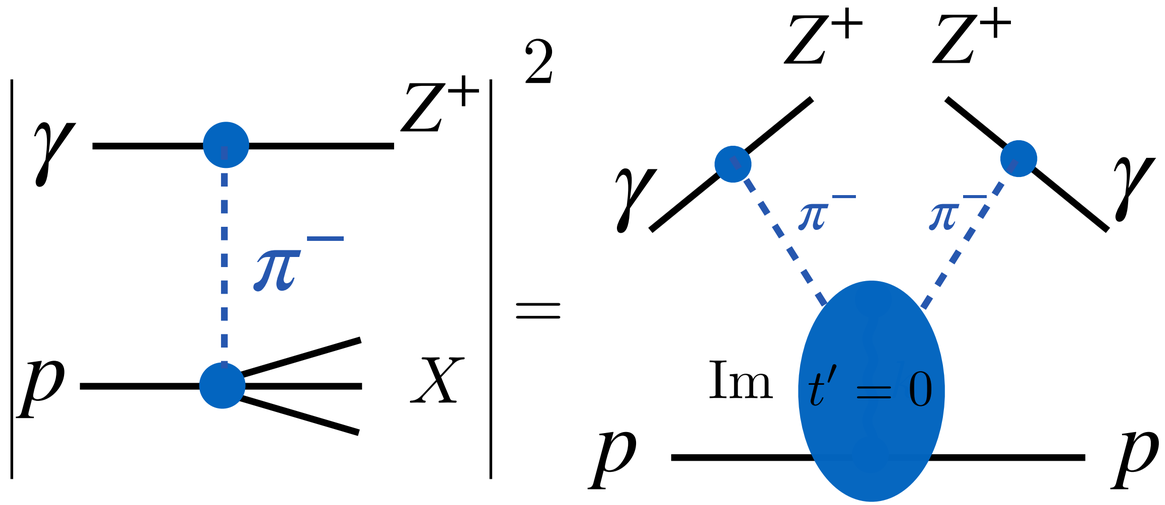


Semi-inclusive $Z^+_{c,b}$ Production @EIC



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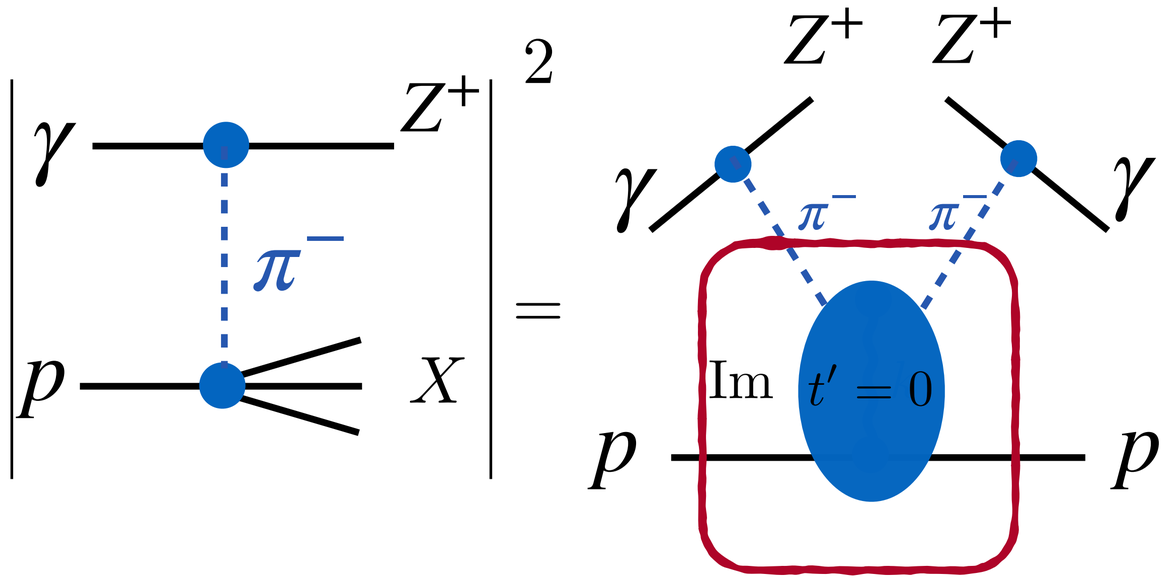

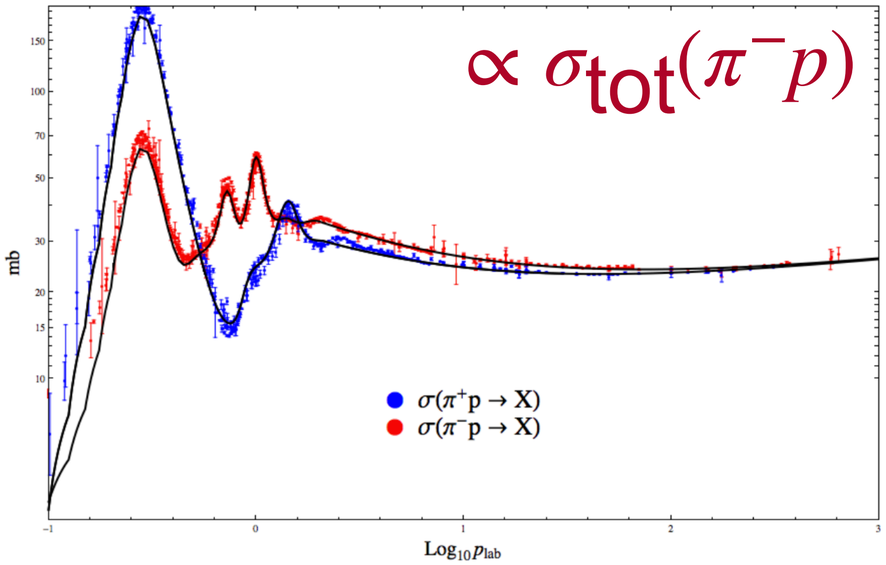

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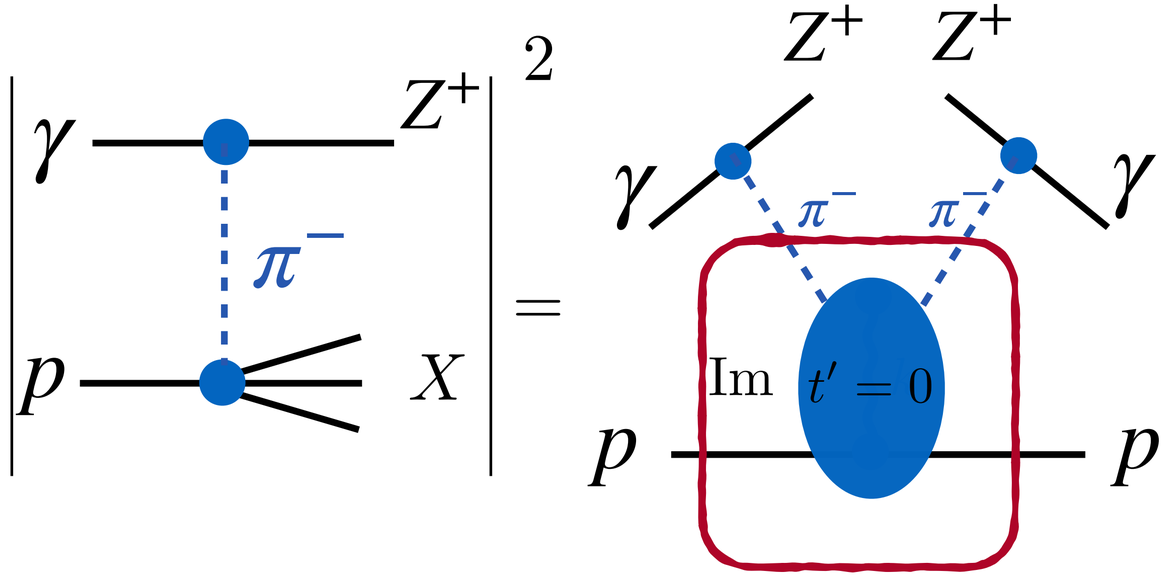

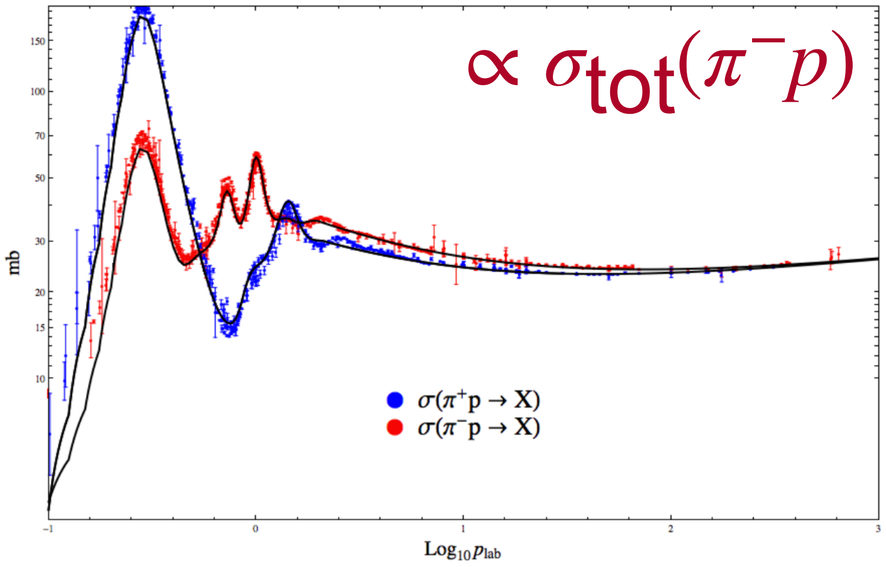

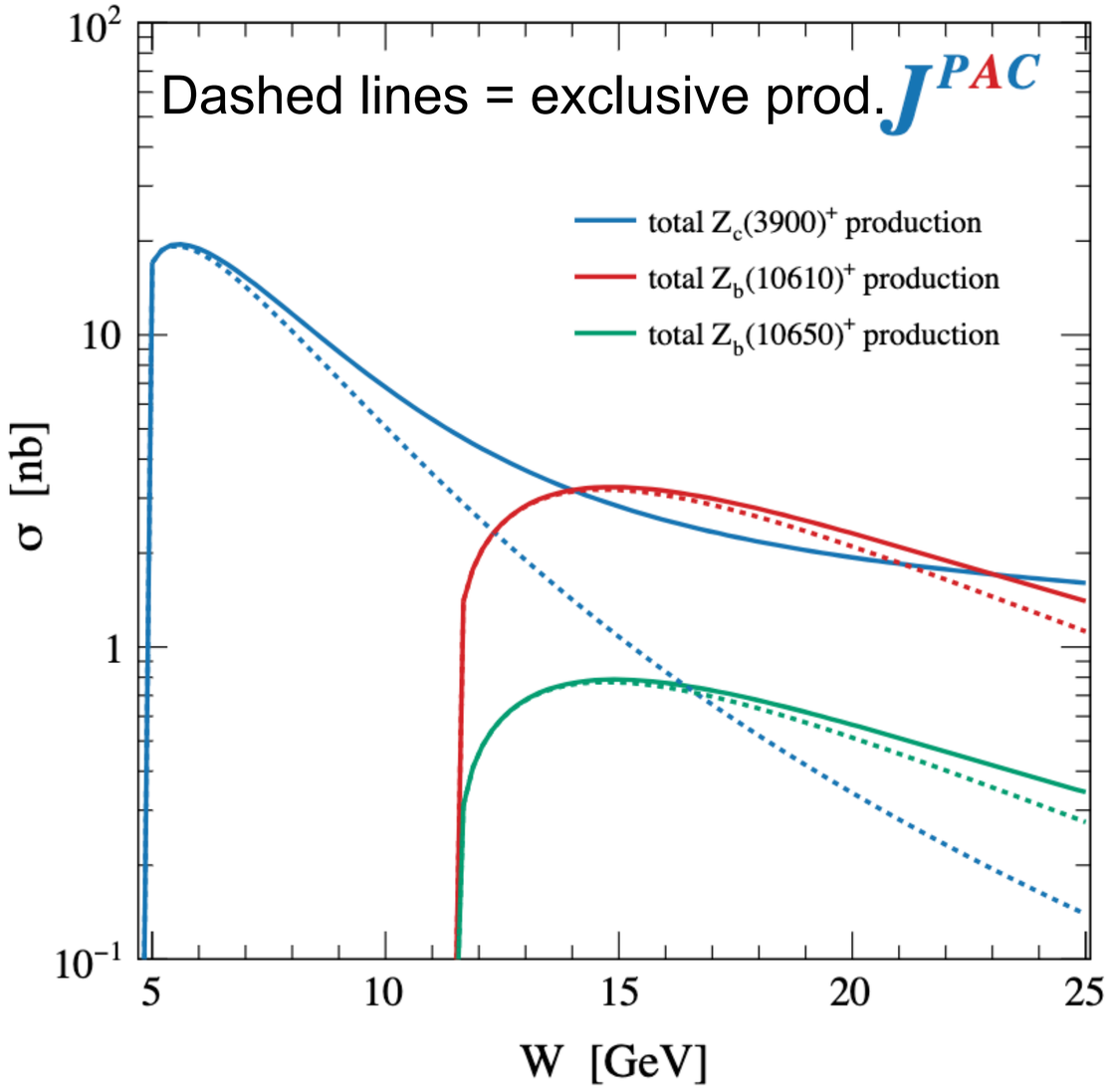

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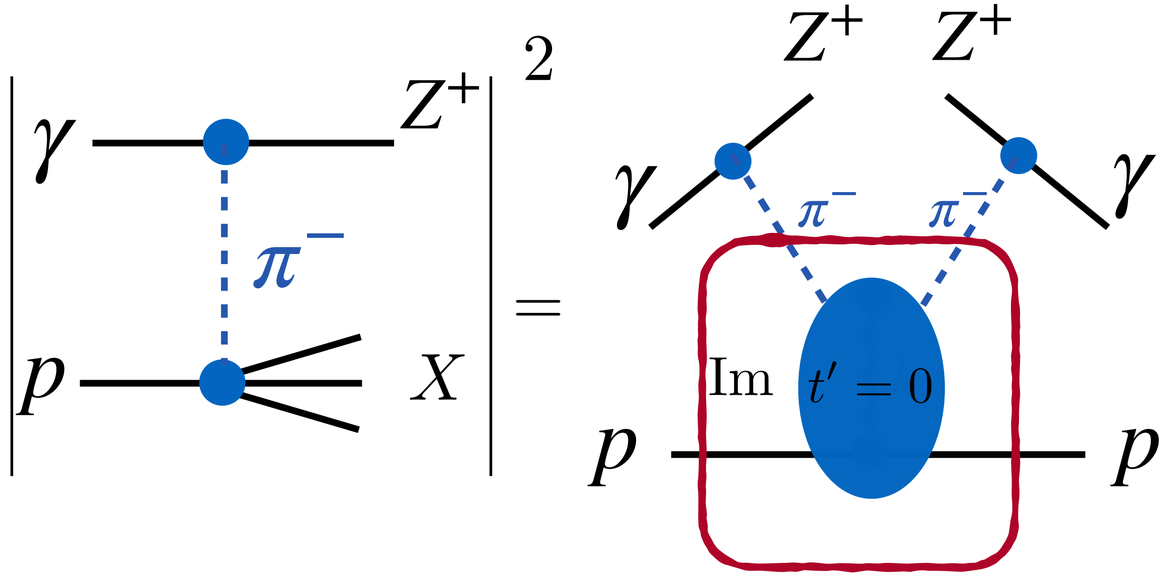
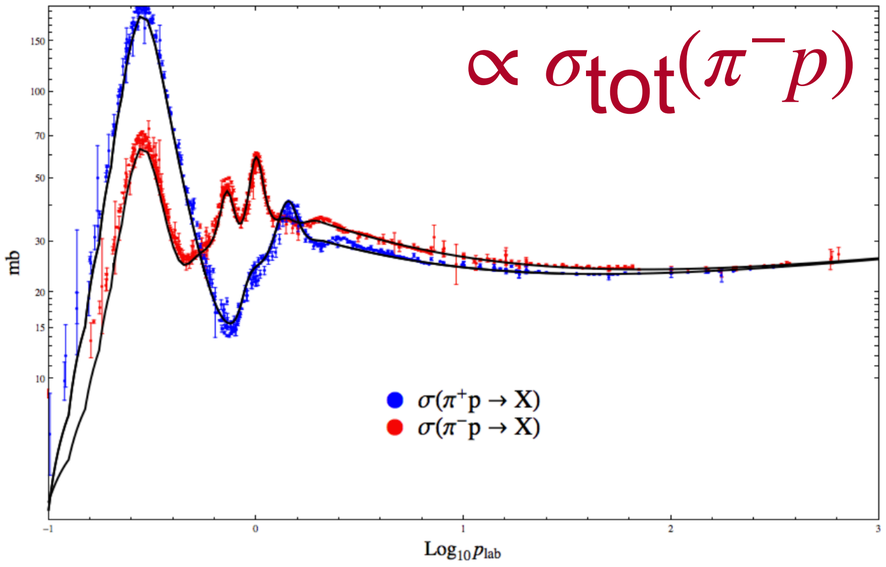
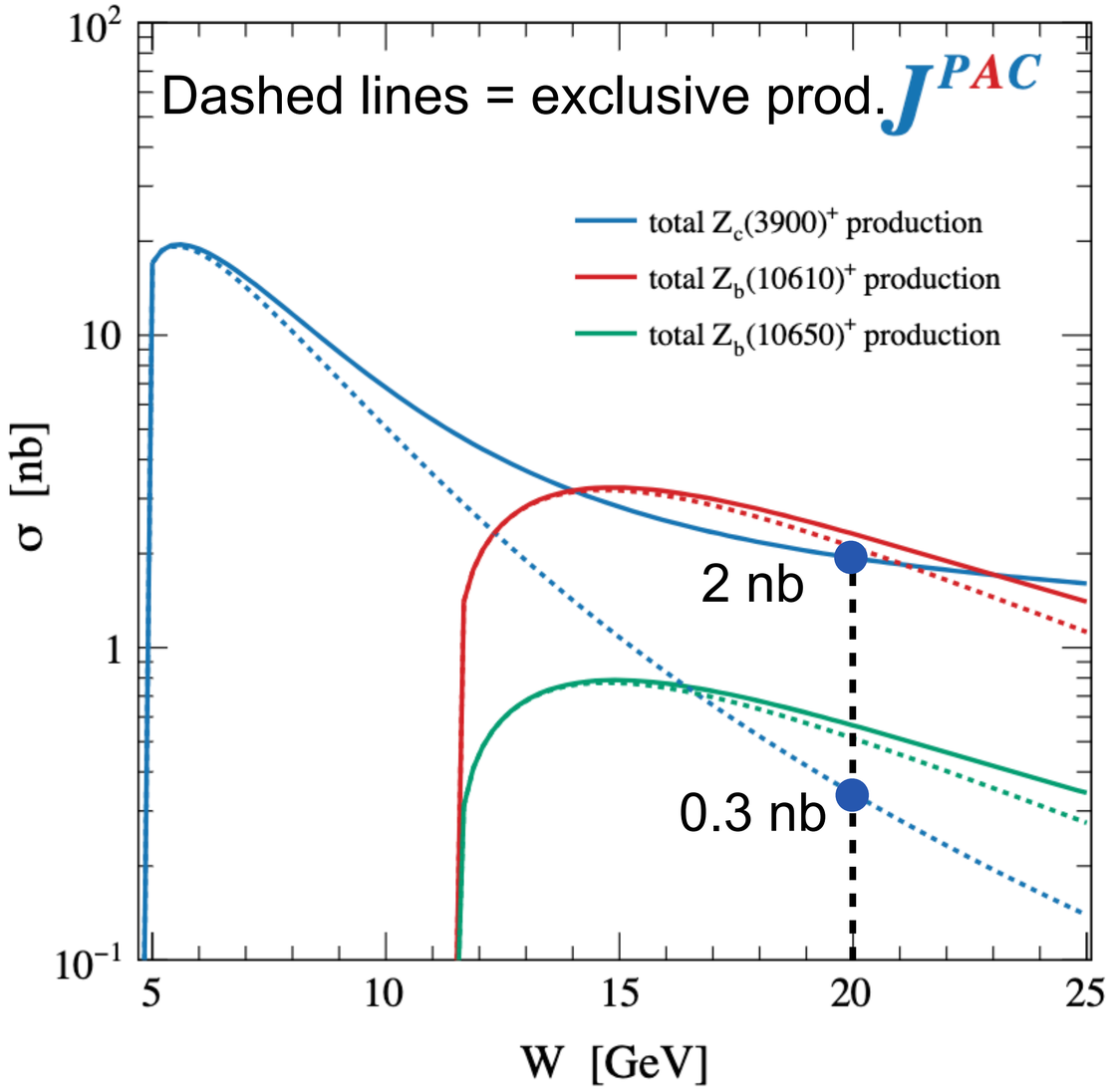
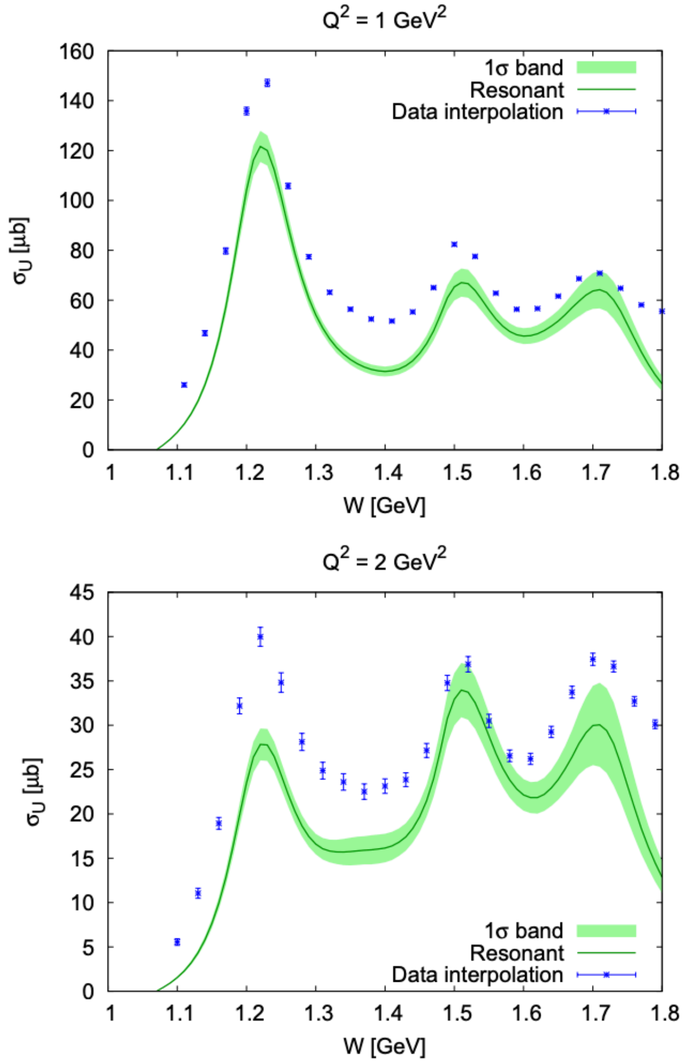




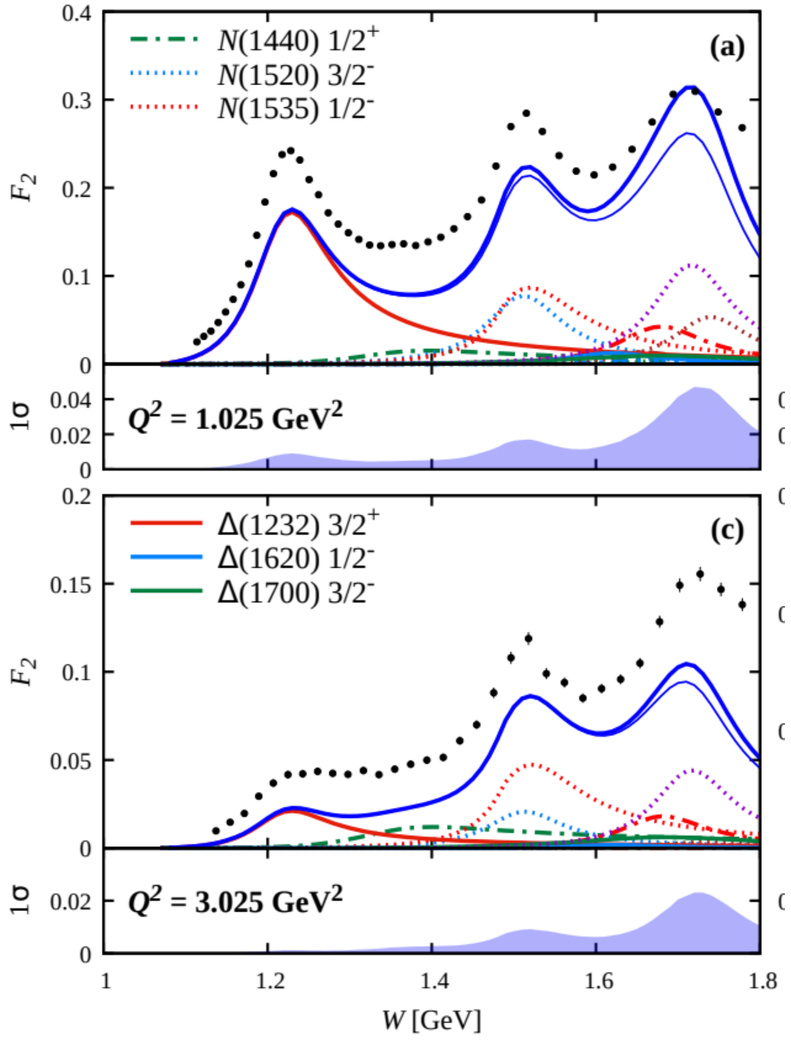


Baryon contribution to structure functions

A. Hiller-Blin et al PRC100 (2019)

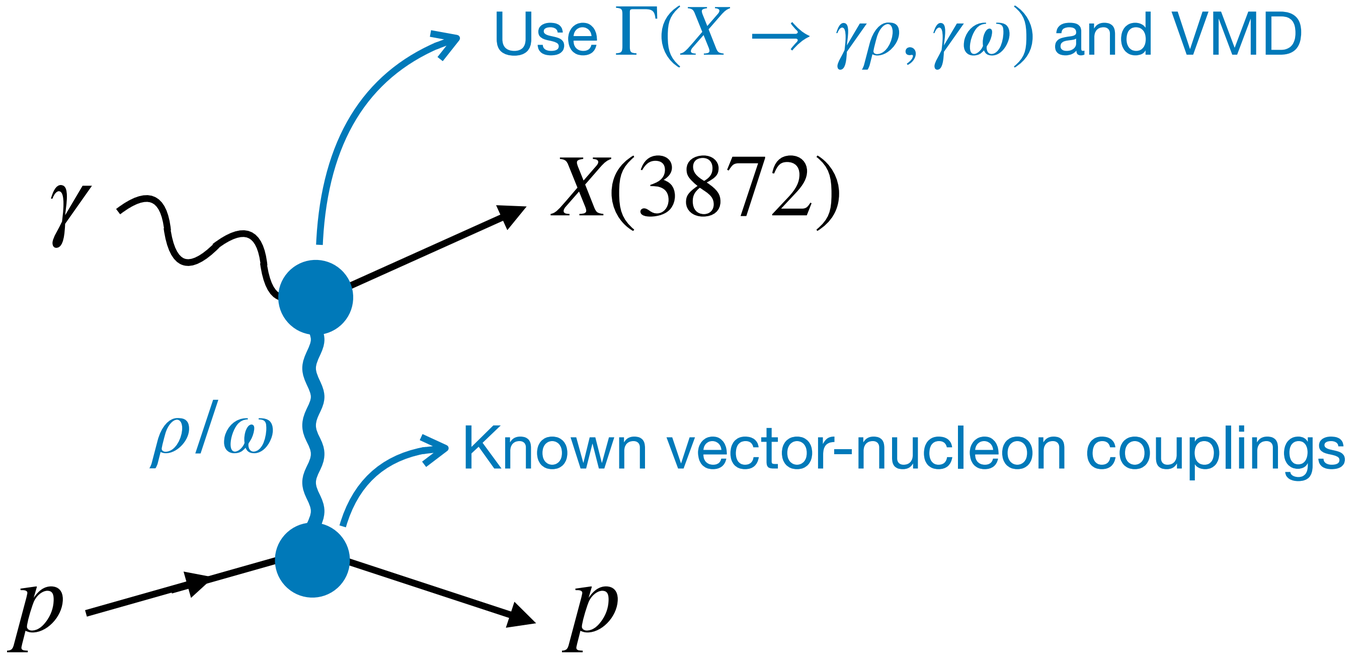


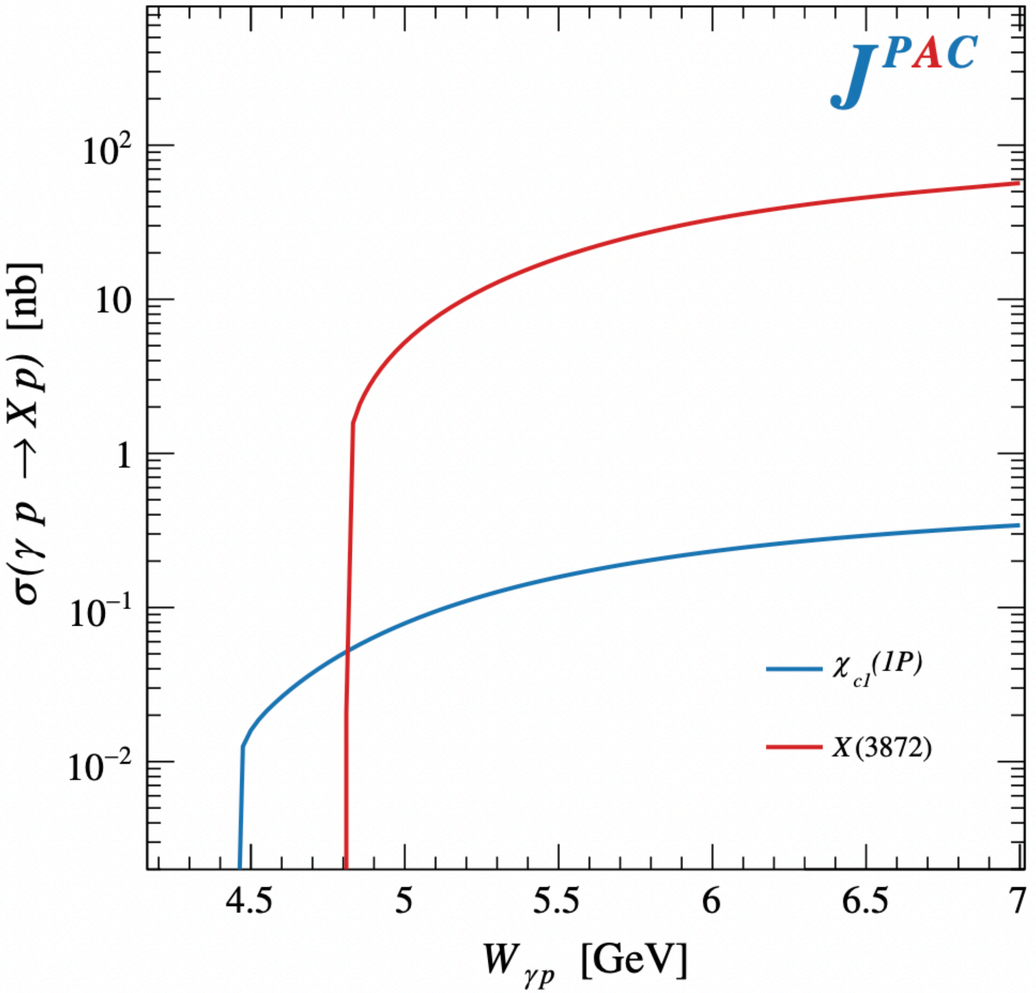
A. Hiller-Blin et al PRC104 (2021)



Exclusive X(3872) Production @EIC

Albaladejo et al (JPAC), PRD102 (2020)





C++ code available online (D. Winney)

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