Two Mesons Photoproduction: Theory and Application

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Joint Physics Analysis Center
Exotic Hadron Topical Collaboration

NSTAR Conference

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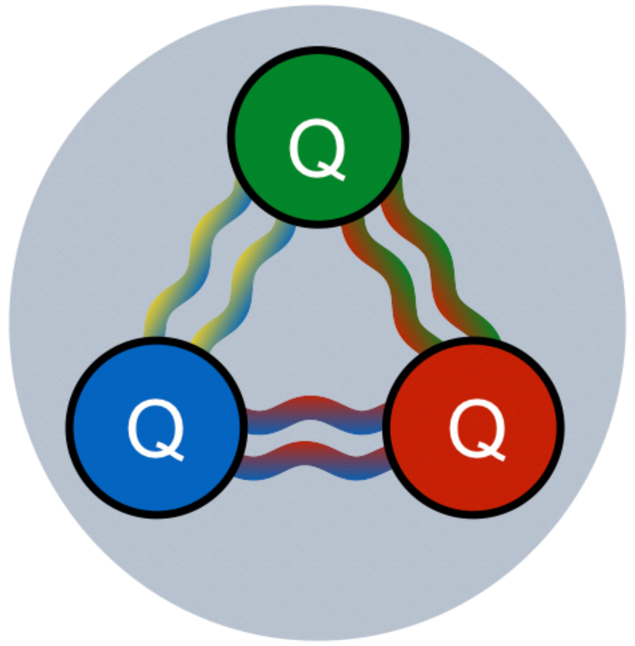
Ordinary and Exotic Hadrons

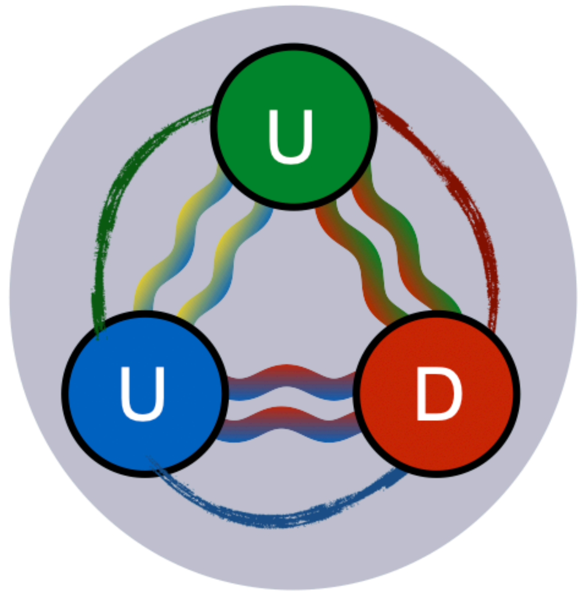
Ordinary baryons



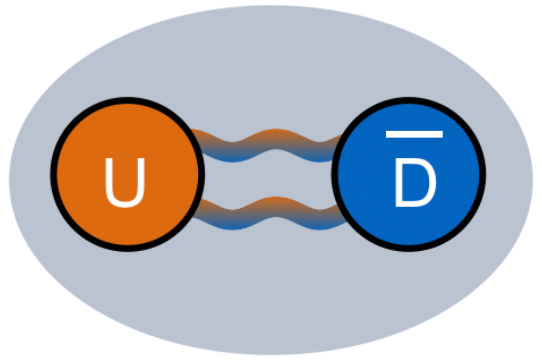
proton	stable
neutron	$\tau \sim 10^{3} s$
baryon Λ	$\tau \sim 10^{-10} s$

Exotic matter

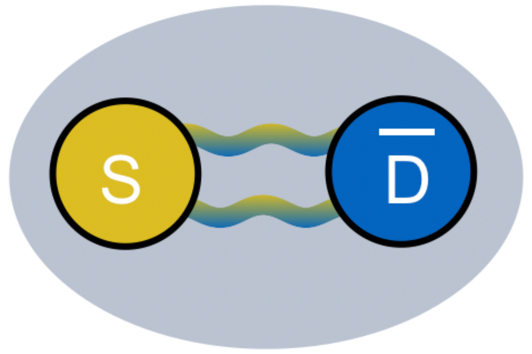
Hybrid baryons



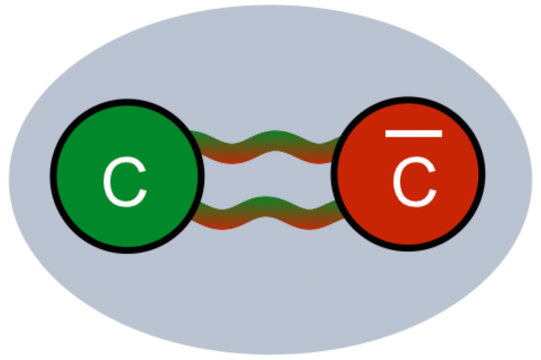
Ordinary mesons



pion $\tau \sim 10^{-8} s$

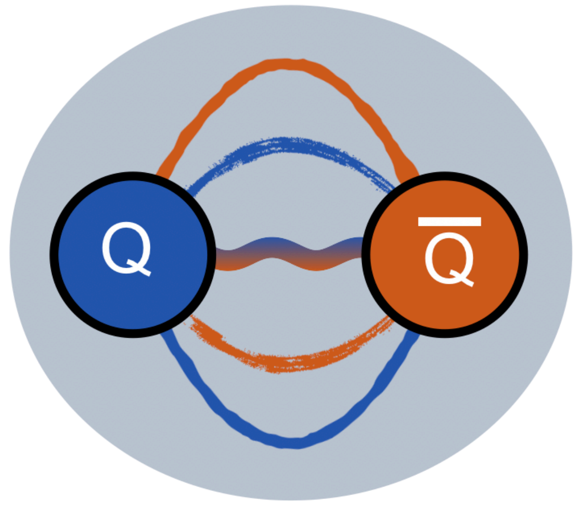


kaon $\tau \sim 10^{-8} s$



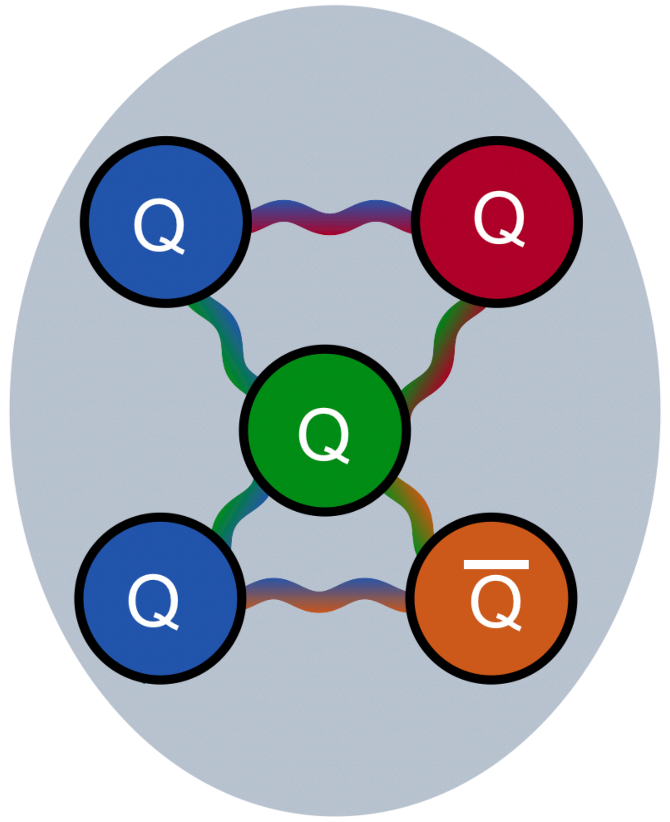
J/ψ $\tau \sim 10^{-20} s$

hybrid mesons

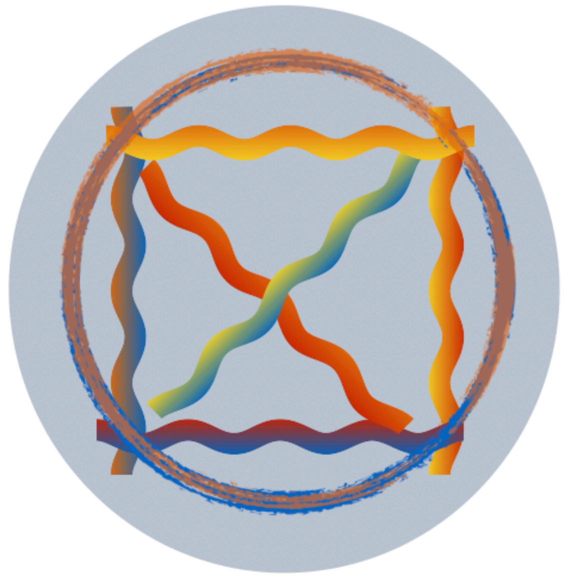


tetraquarks

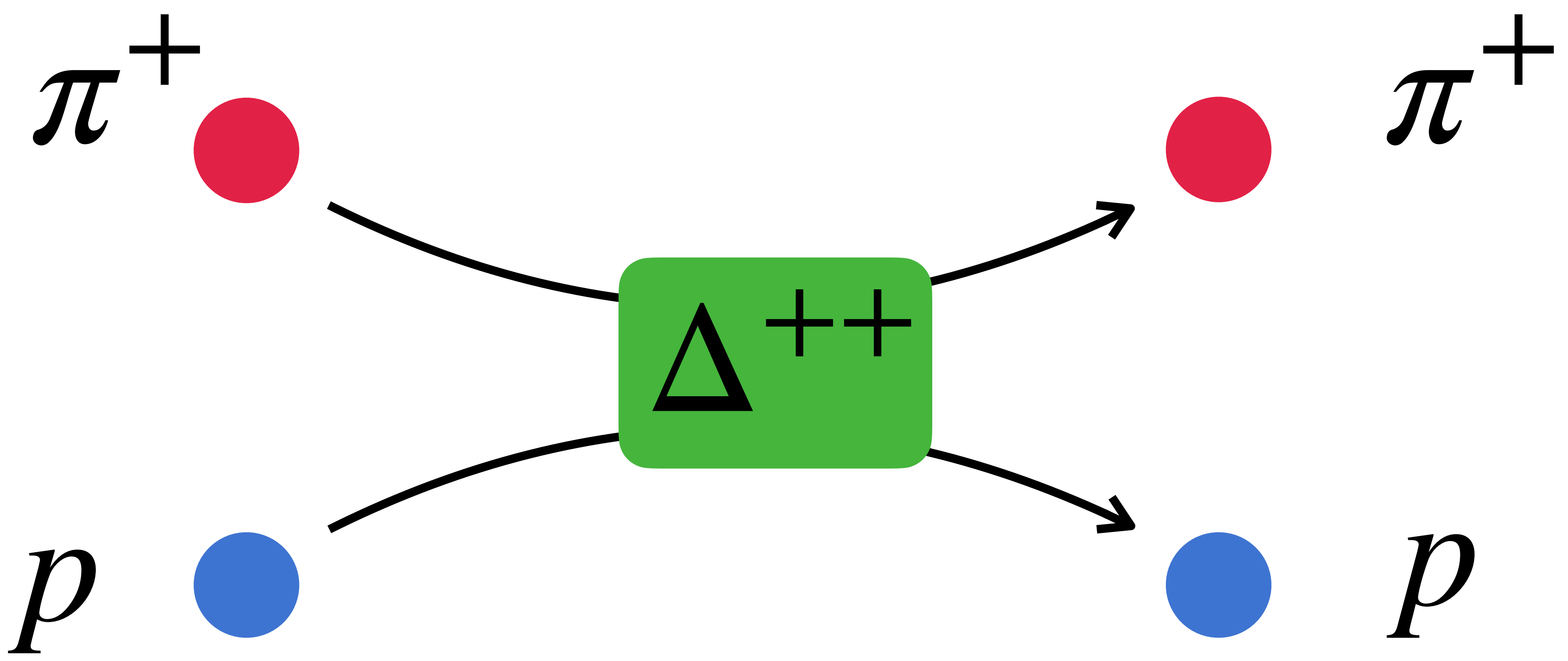
pentaquarks

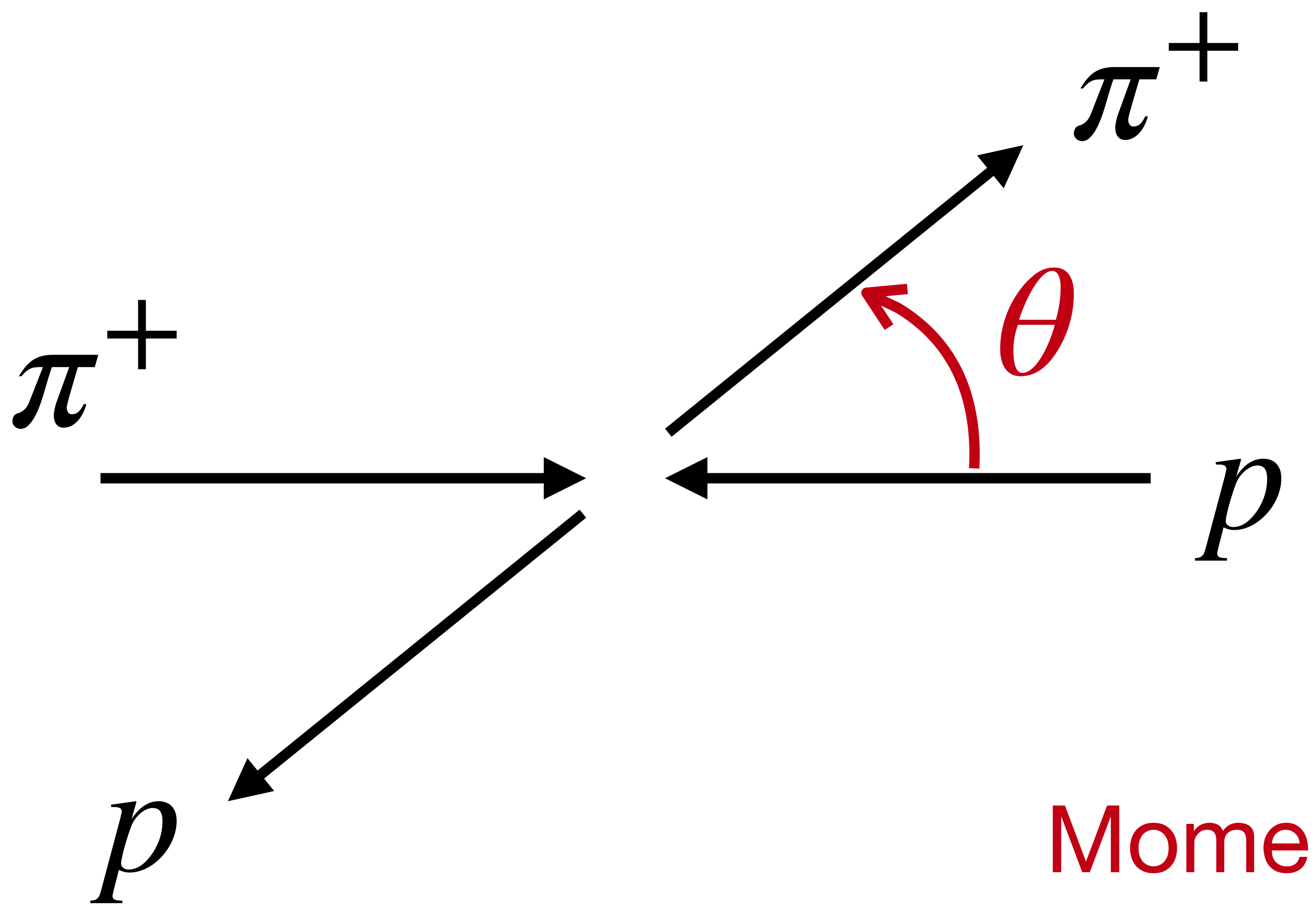


glueballs



Observables and Moments





Two scattering amplitudes of 2 variables

$$A_\pm(s,z) = \sum_{J=1/2}^{\infty} (2J+1)\, a_\pm^J(s)\, d^J_{\frac{1}{2},\pm\frac{1}{2}}(z)$$

$(z = \cos\theta)$

Two observables of 2 variables

$$\frac{\mathrm{d}\sigma}{\mathrm{d}z} = \frac{1}{16\pi^2 s}\left[\,|A_+(s,z)|^2 + |A_-(s,z)|^2\right]$$

$$P\frac{\mathrm{d}\sigma}{\mathrm{d}z} = \frac{1}{16\pi^2 s}\mathrm{Im}\left[A_+(s,z)A_-^*(s,z)\right]$$

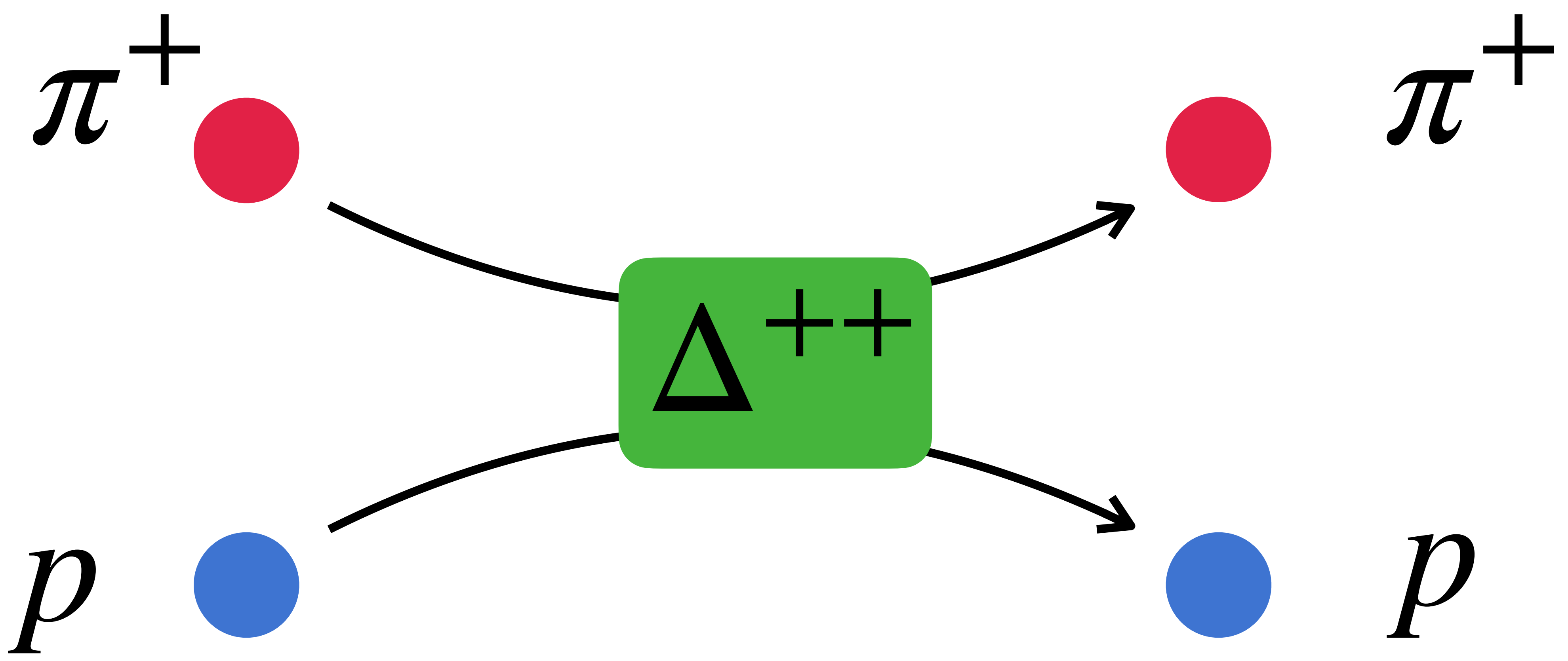
Two unknown (and arbitrary) phases

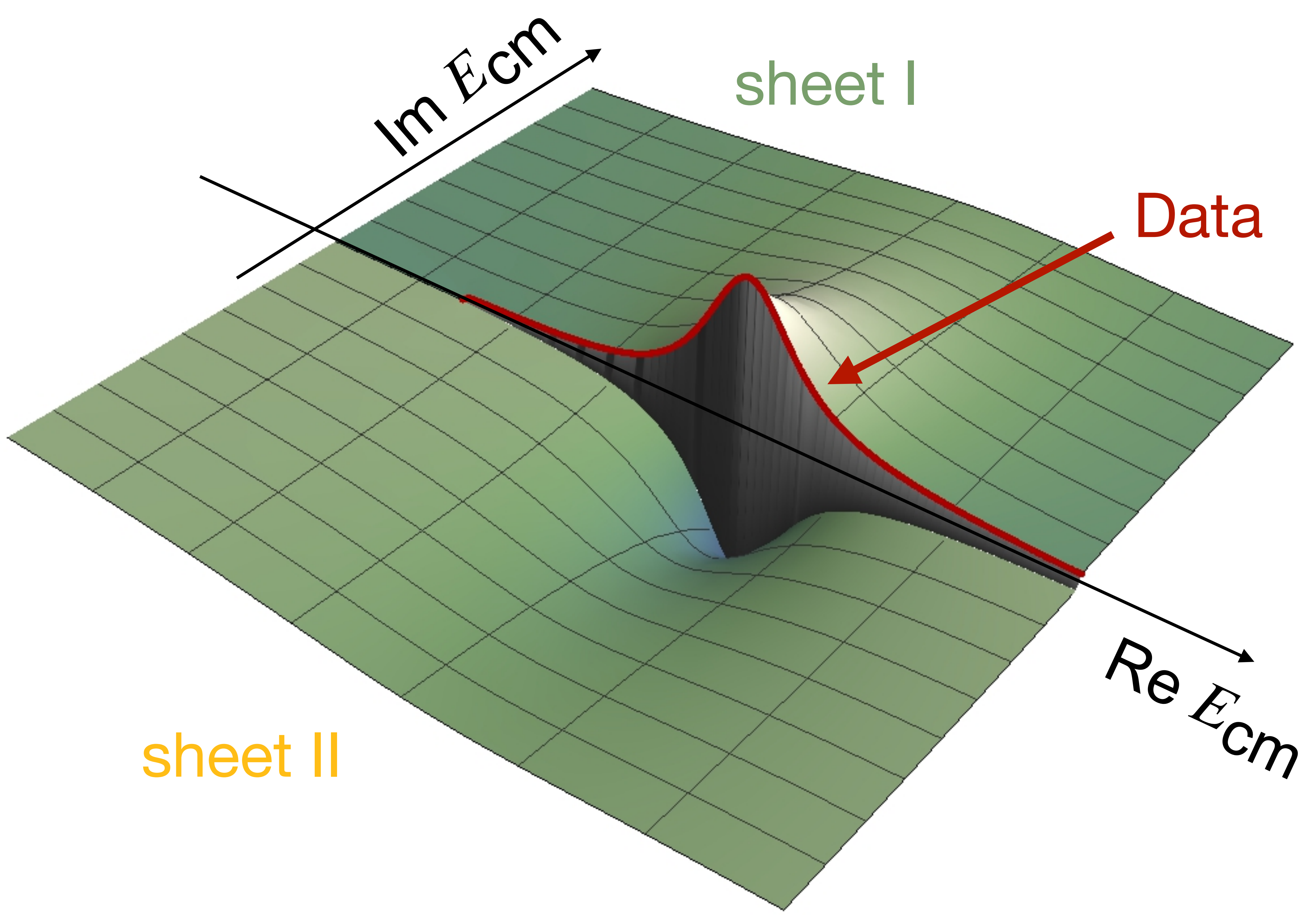
Moment expansion:

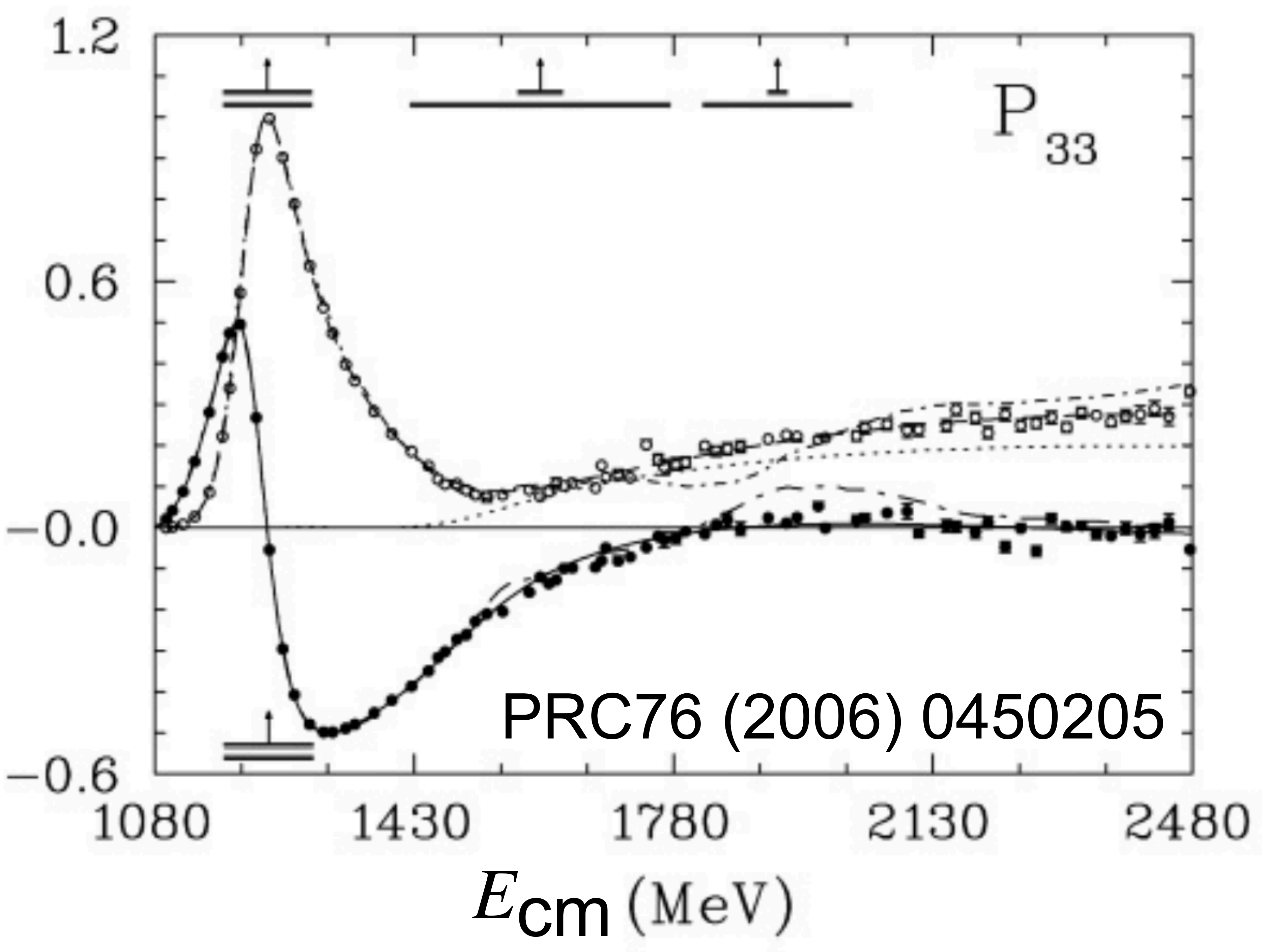
Finite number of H_L

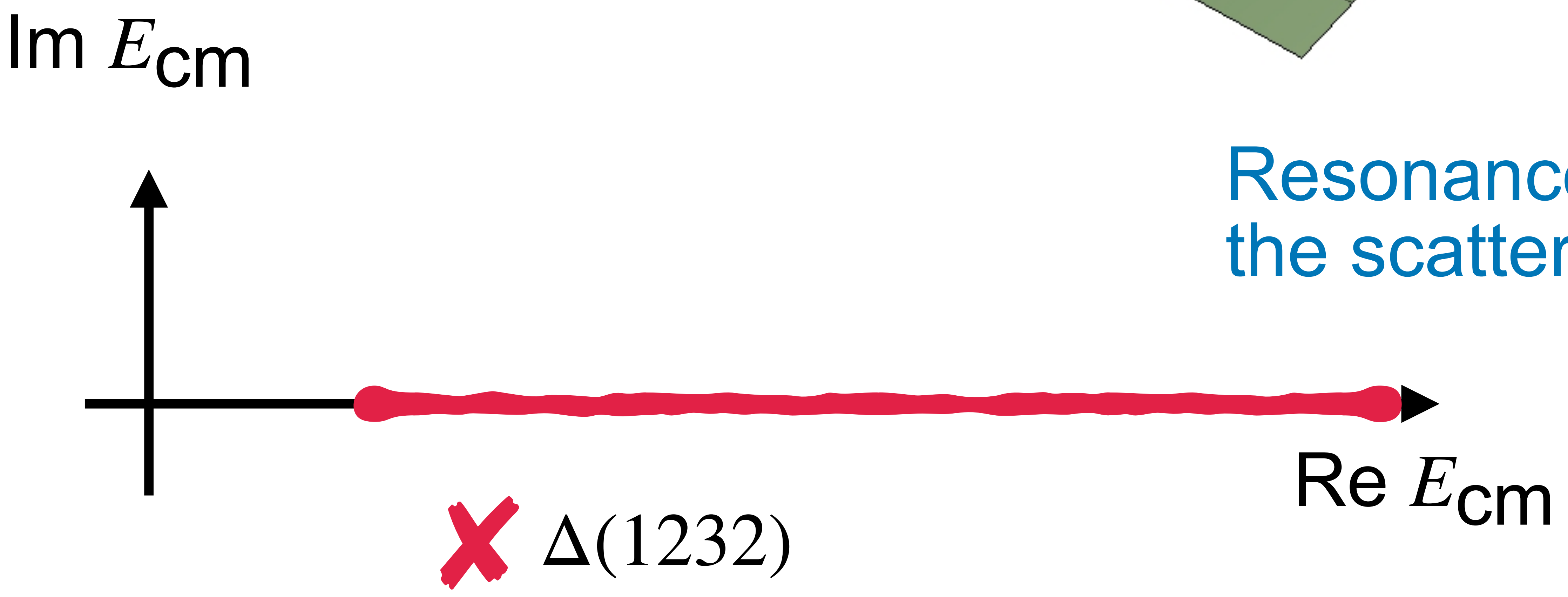
$$\frac{\mathrm{d}\sigma}{\mathrm{d}z} = \sum_{L=0}^{\infty} (2L+1)\, H_L(s)\, P_L(z)$$

What's a resonance?





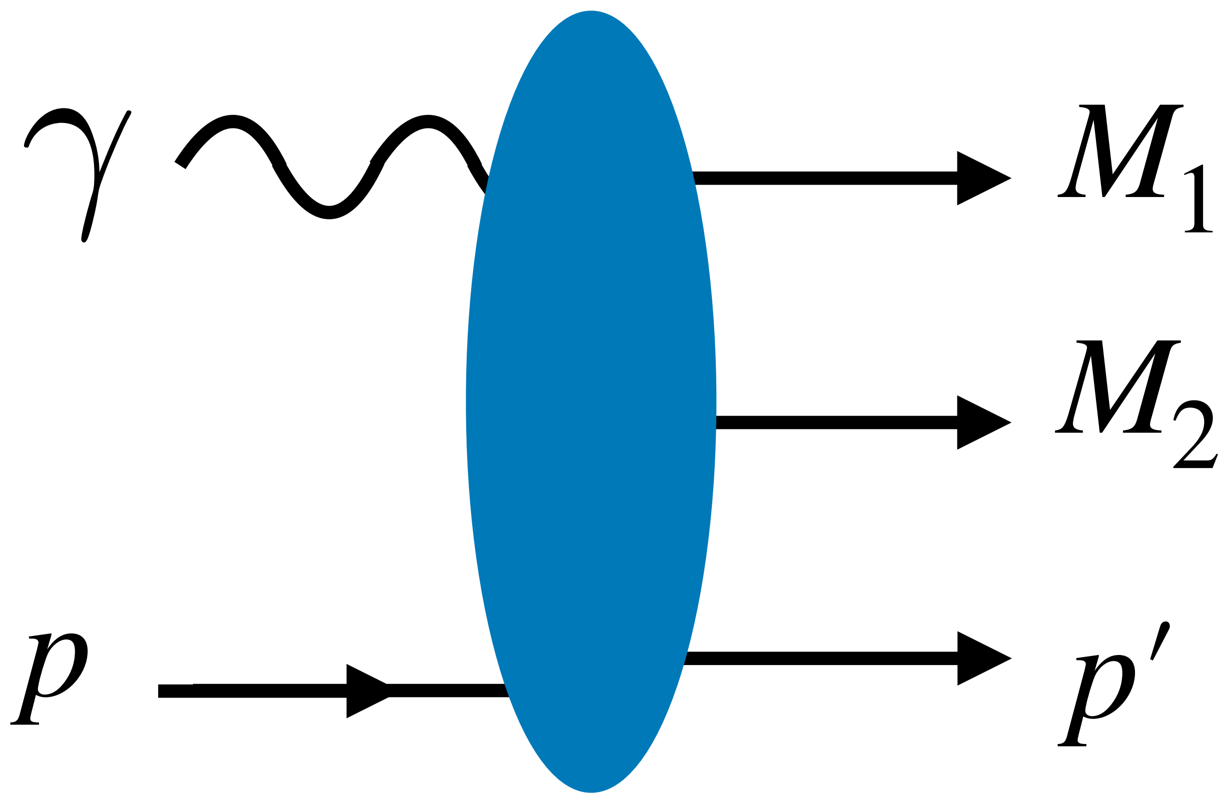




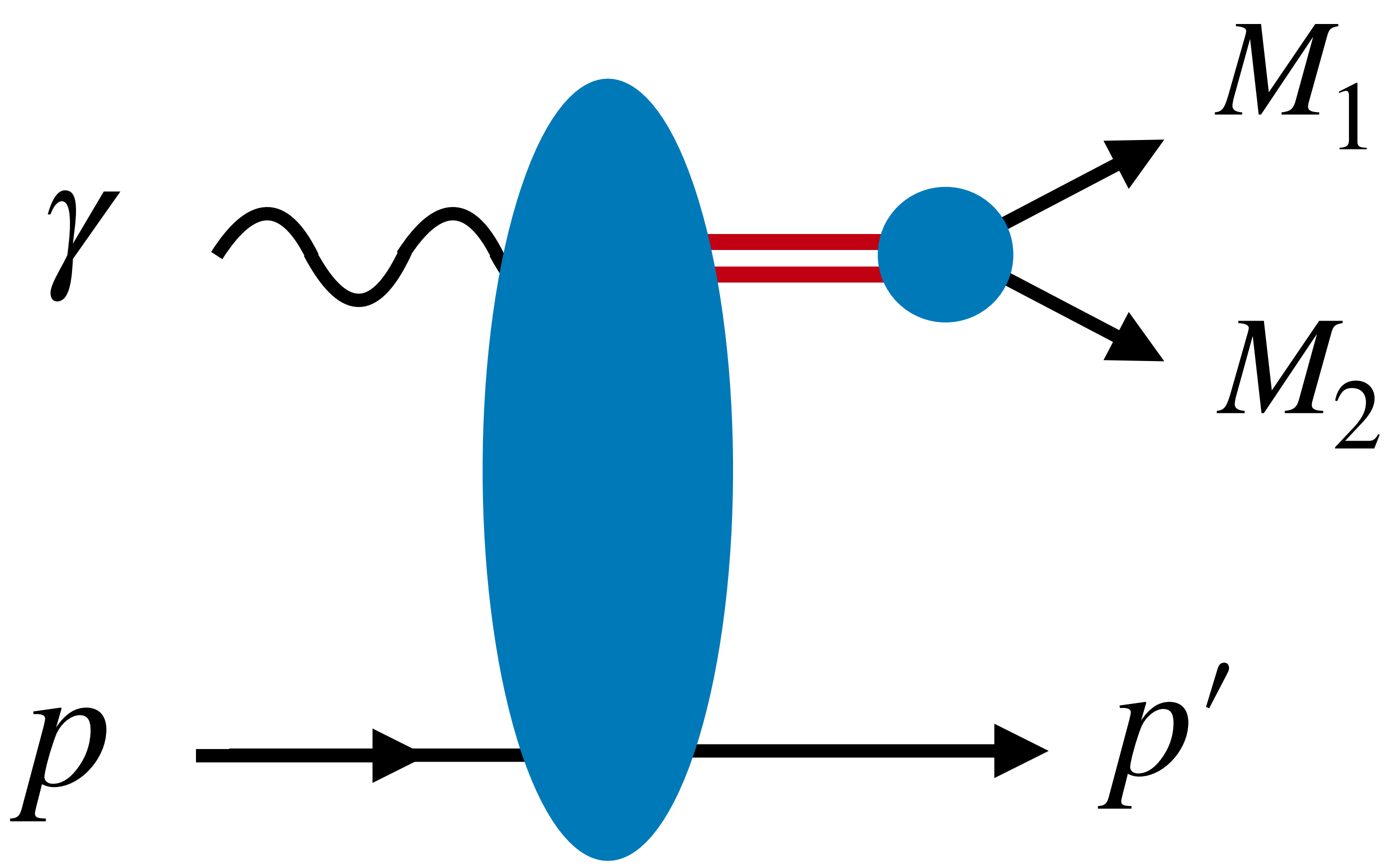
Resonances are poles of the scattering amplitude

Two Meson Photoproduction

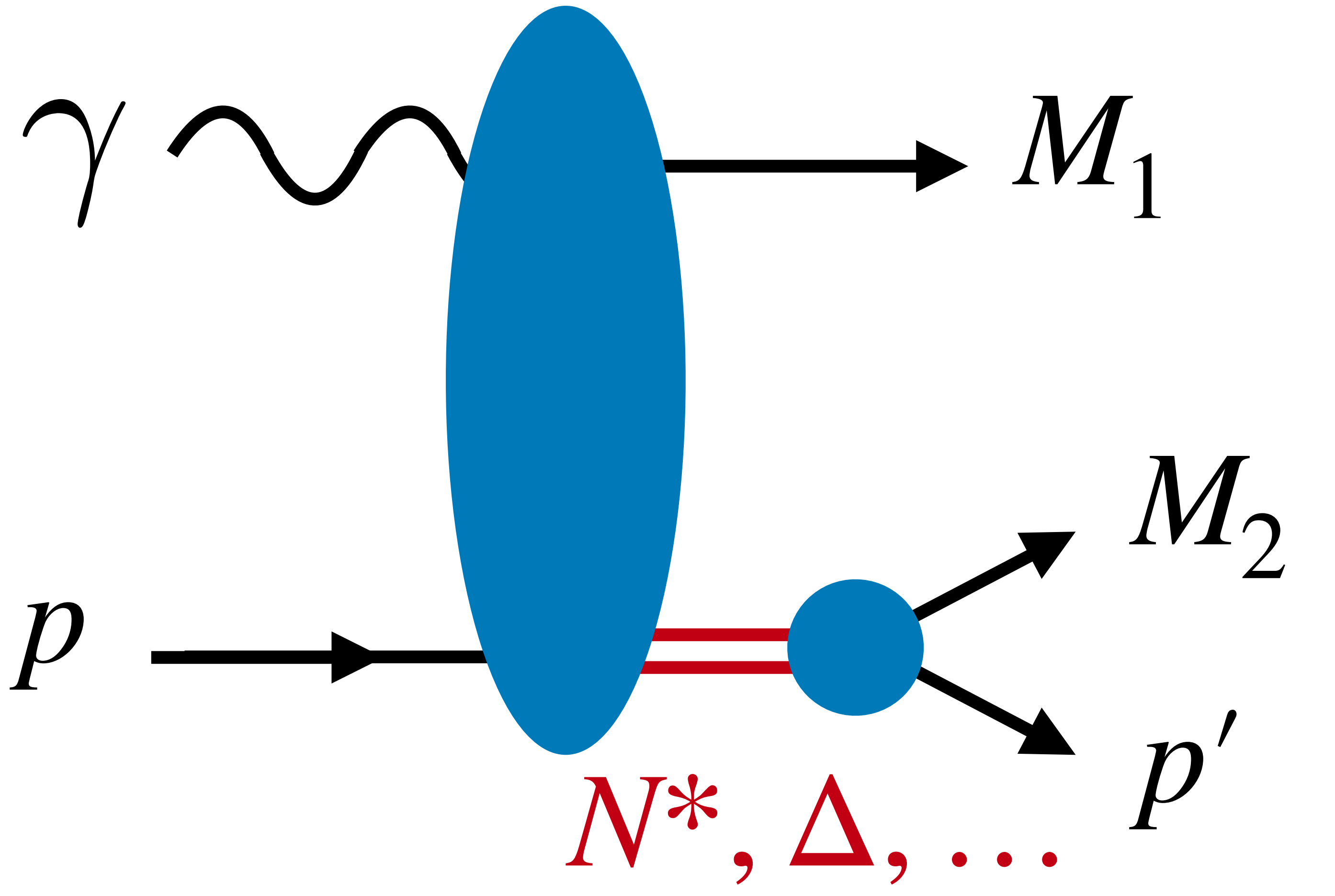
Why 2-meson photoproduction?



Meson spectroscopy



Baryon spectroscopy

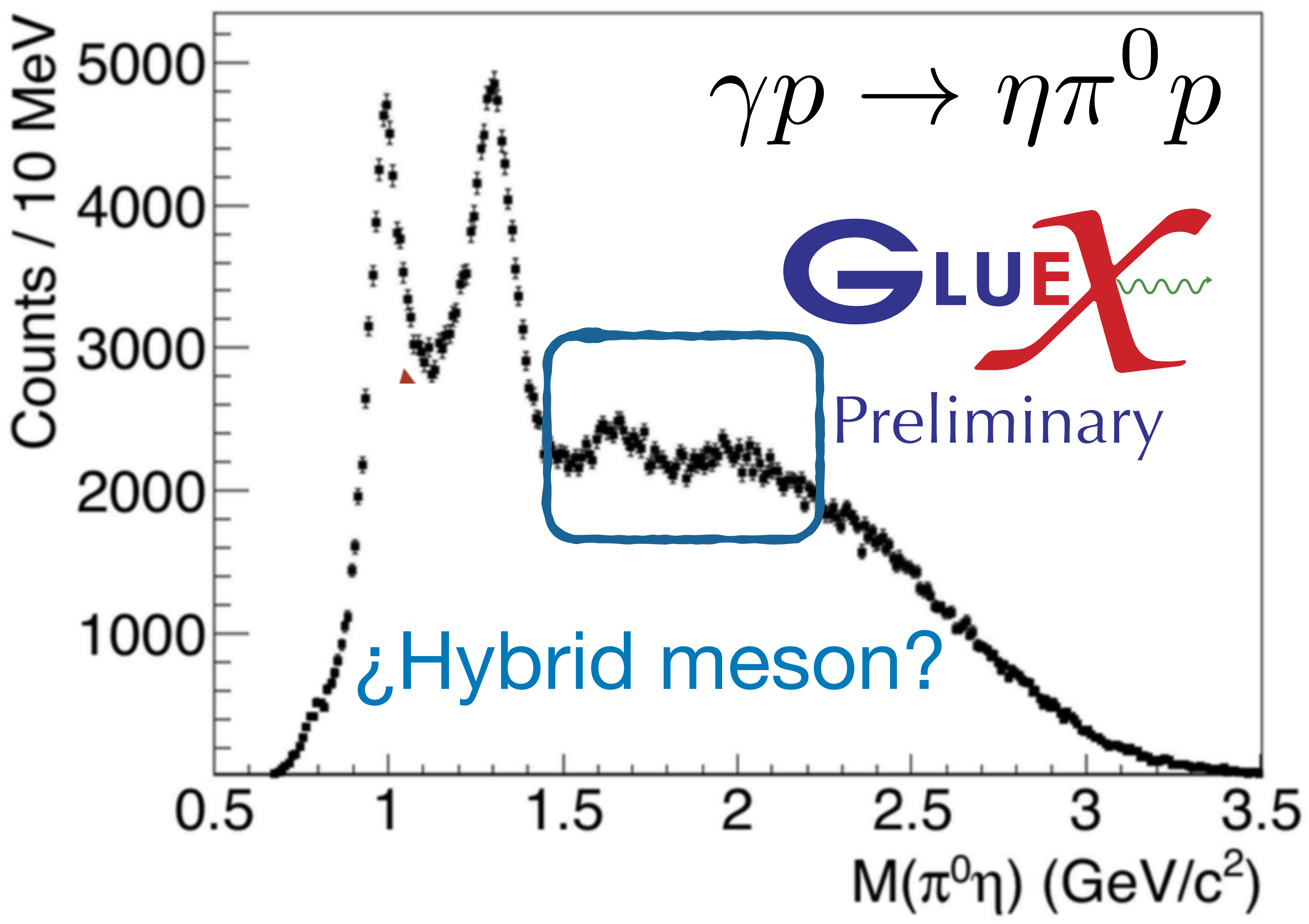


Five independent variables: $s, t, m, \Omega = (\theta, \phi)$

Eight independent amplitudes:

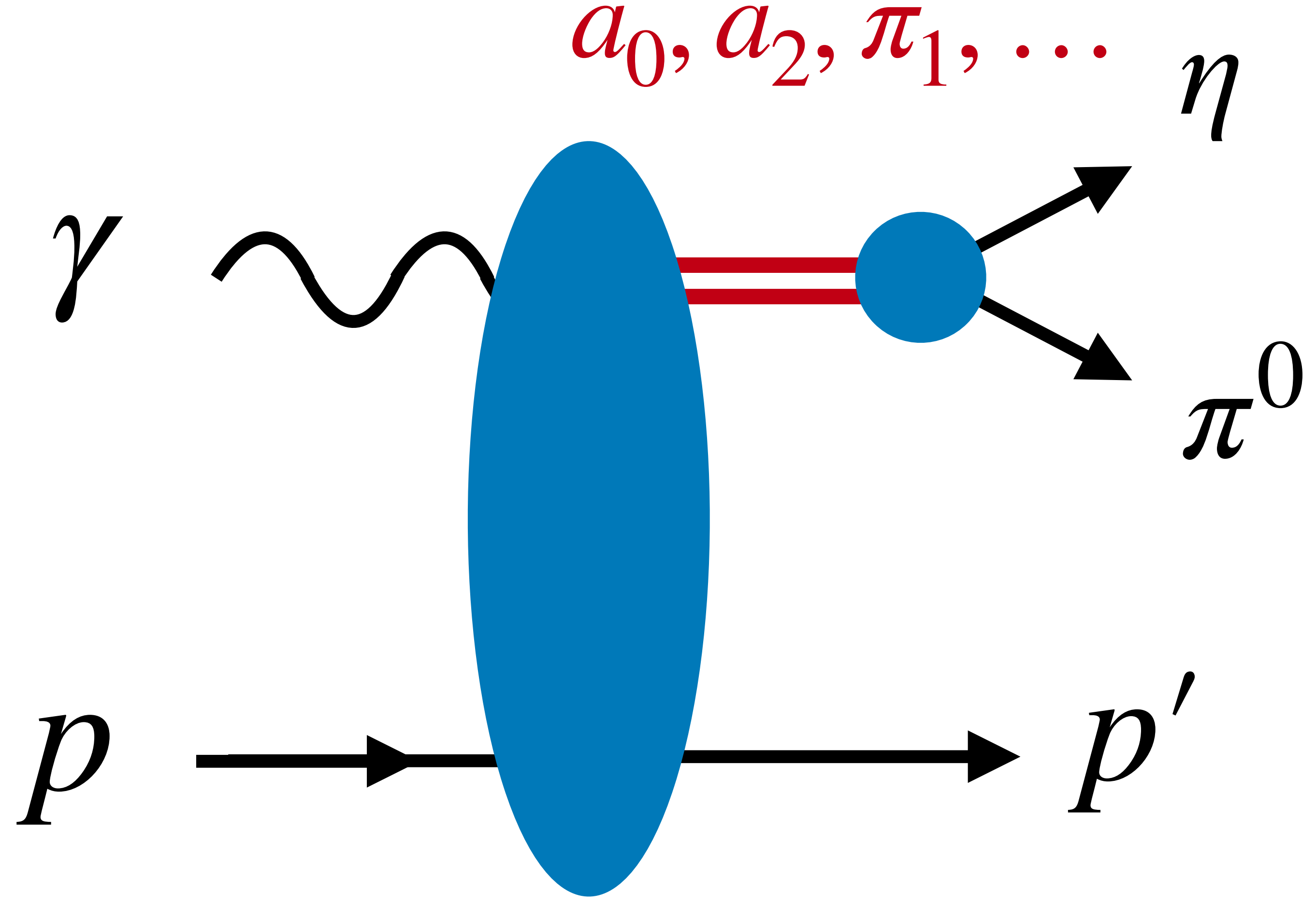
$$\lambda_\gamma = \pm 1,\ \lambda_1 = \pm 1/2,\ \lambda_2 = \pm 1/2$$

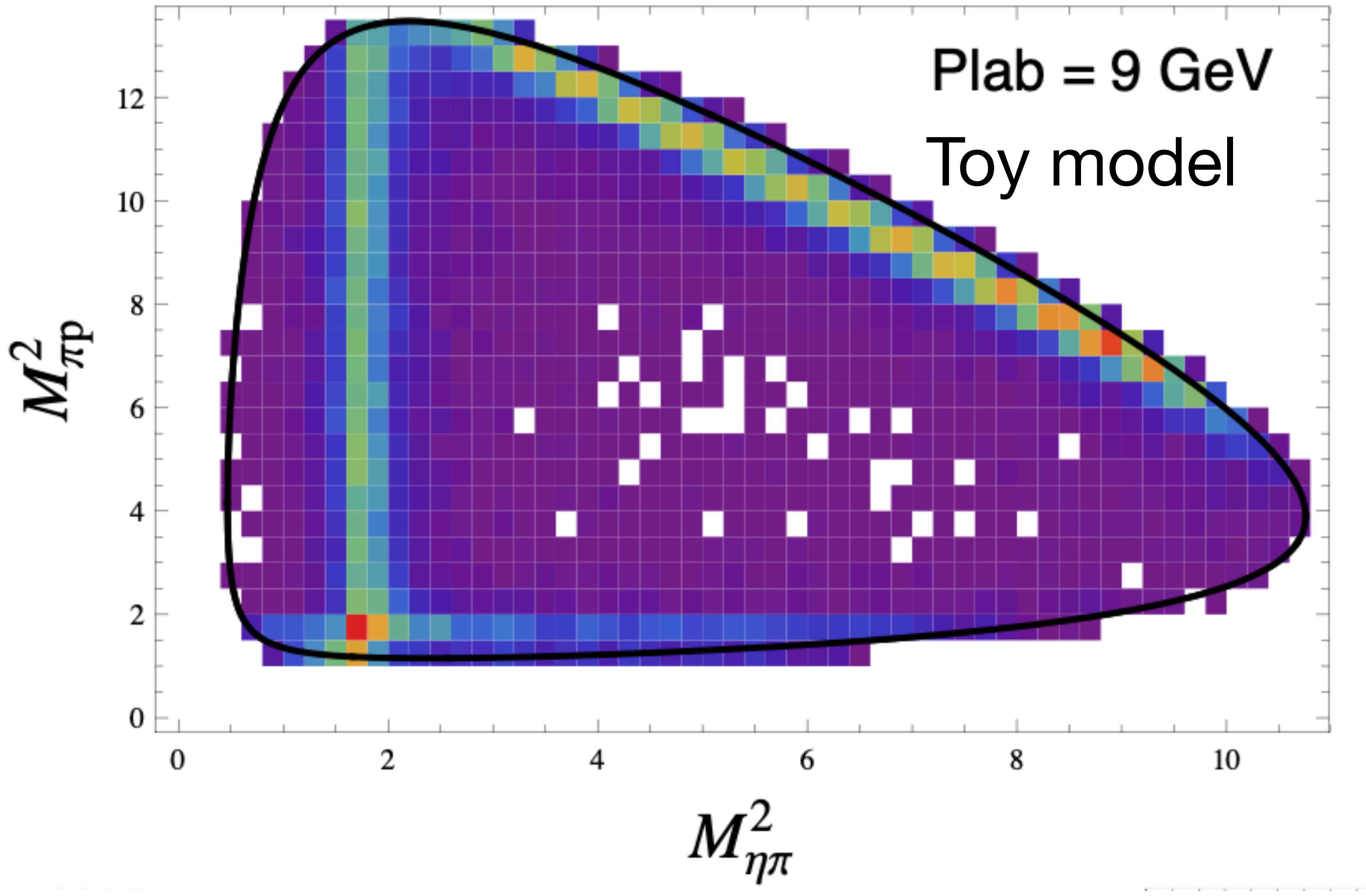
Two Meson Photoproduction



Identifying exotic meson require not only study angular distribution but also understand production mechanisms

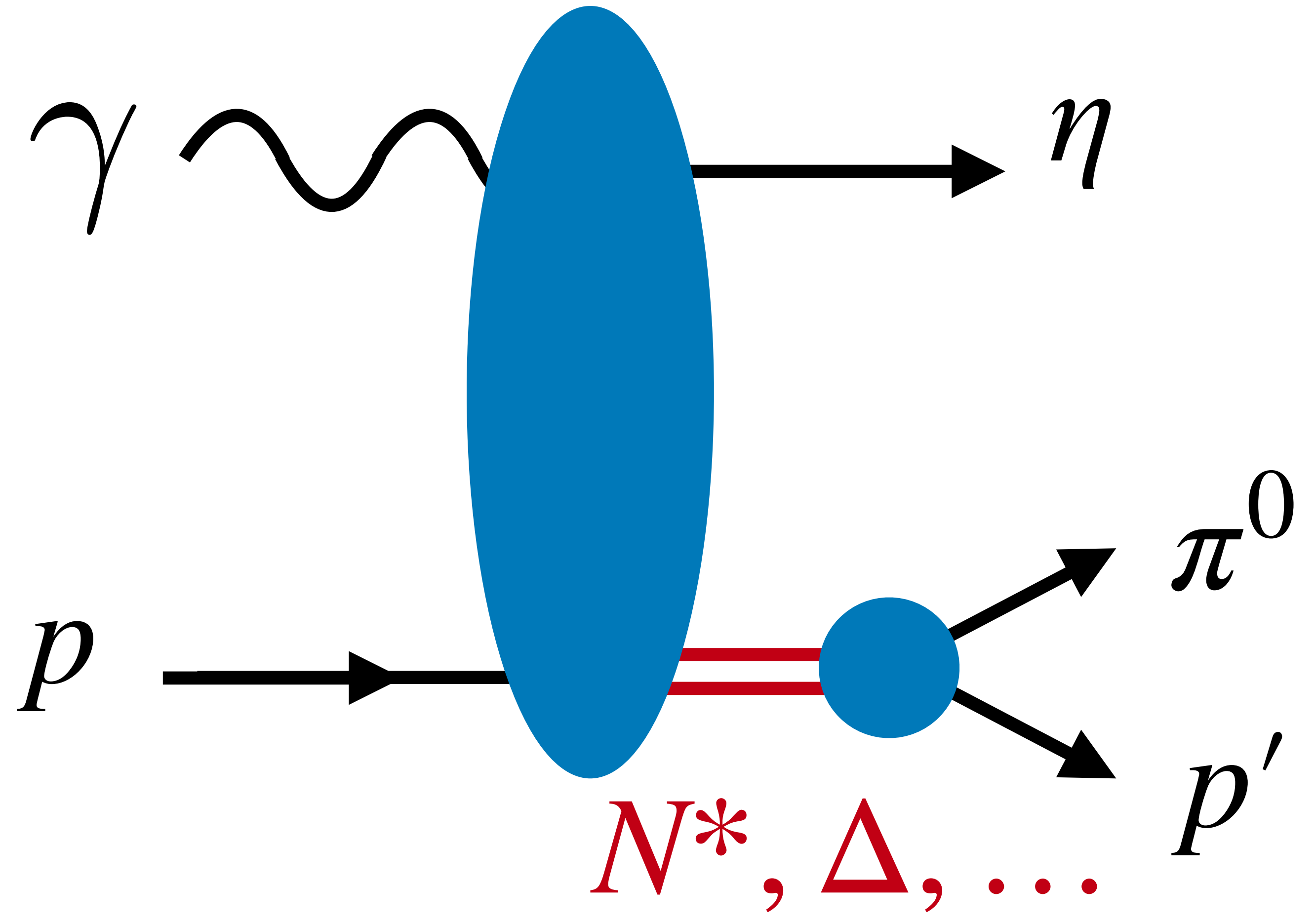
Meson spectroscopy





Baryon resonances interfere with all meson resonances

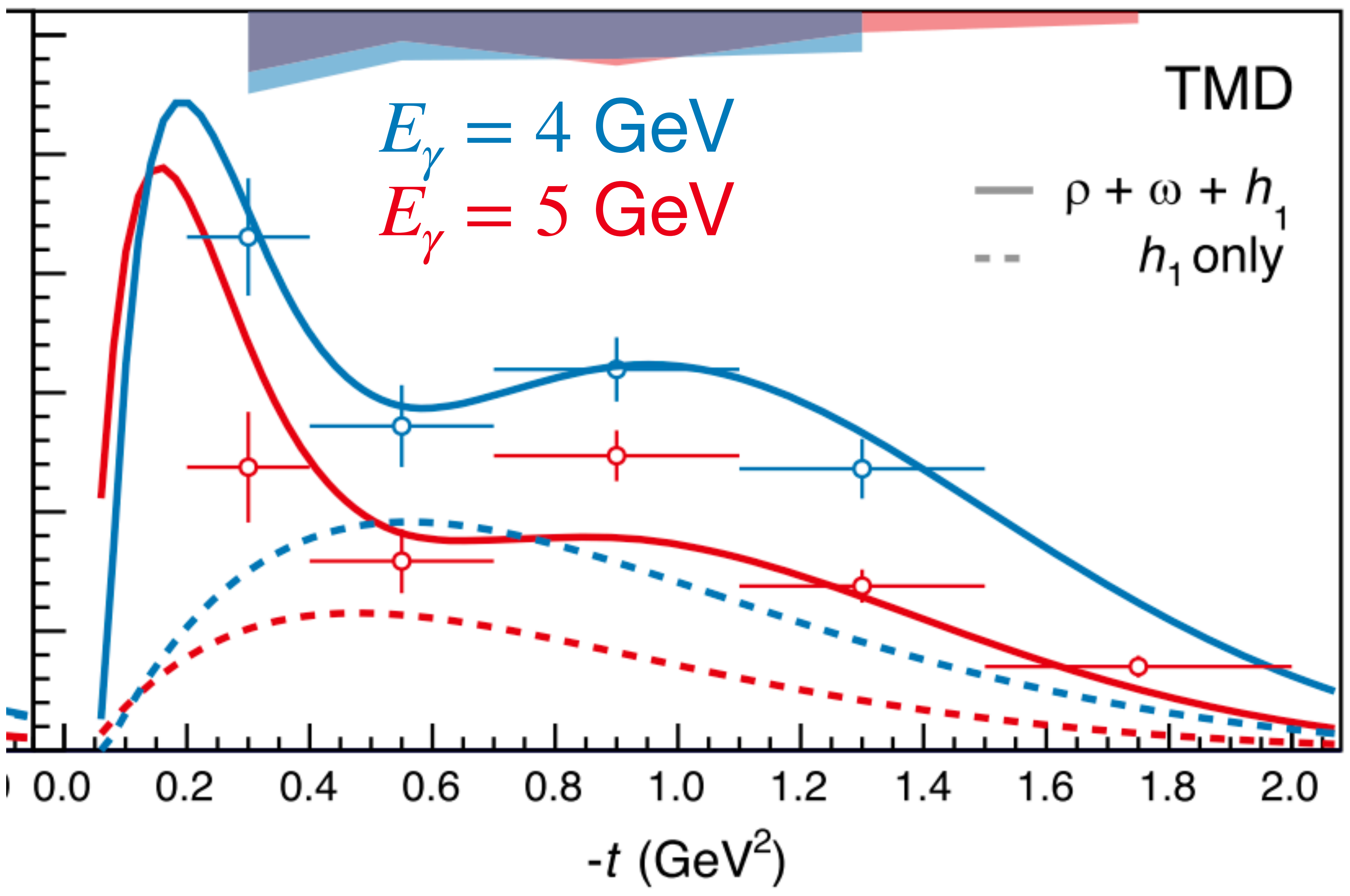
Baryon spectroscopy



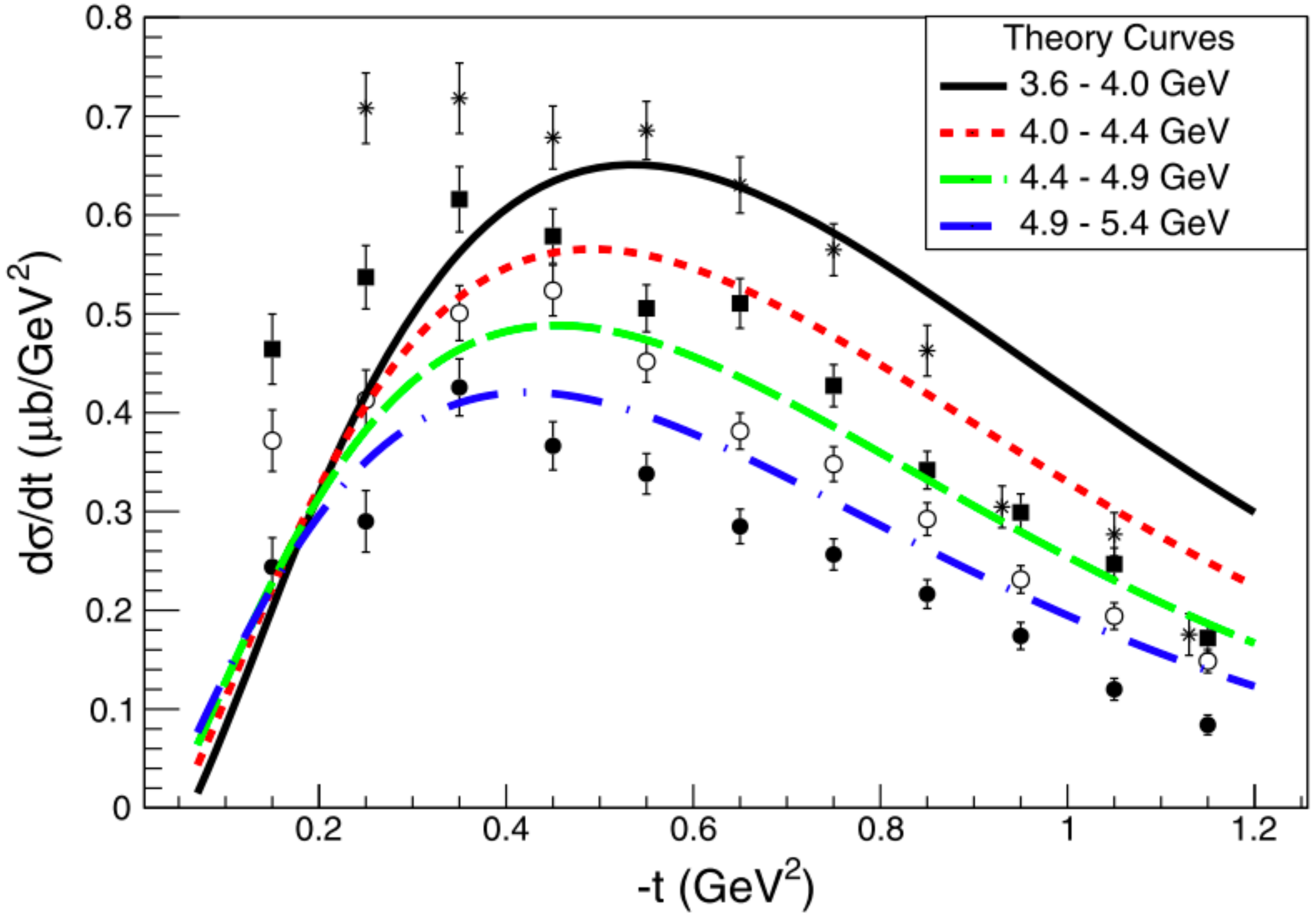
Tensor Meson Photoproduction @CLAS

VM et al (JPAC) PRD102 (2020)

CLAS PRC 102 (2020)

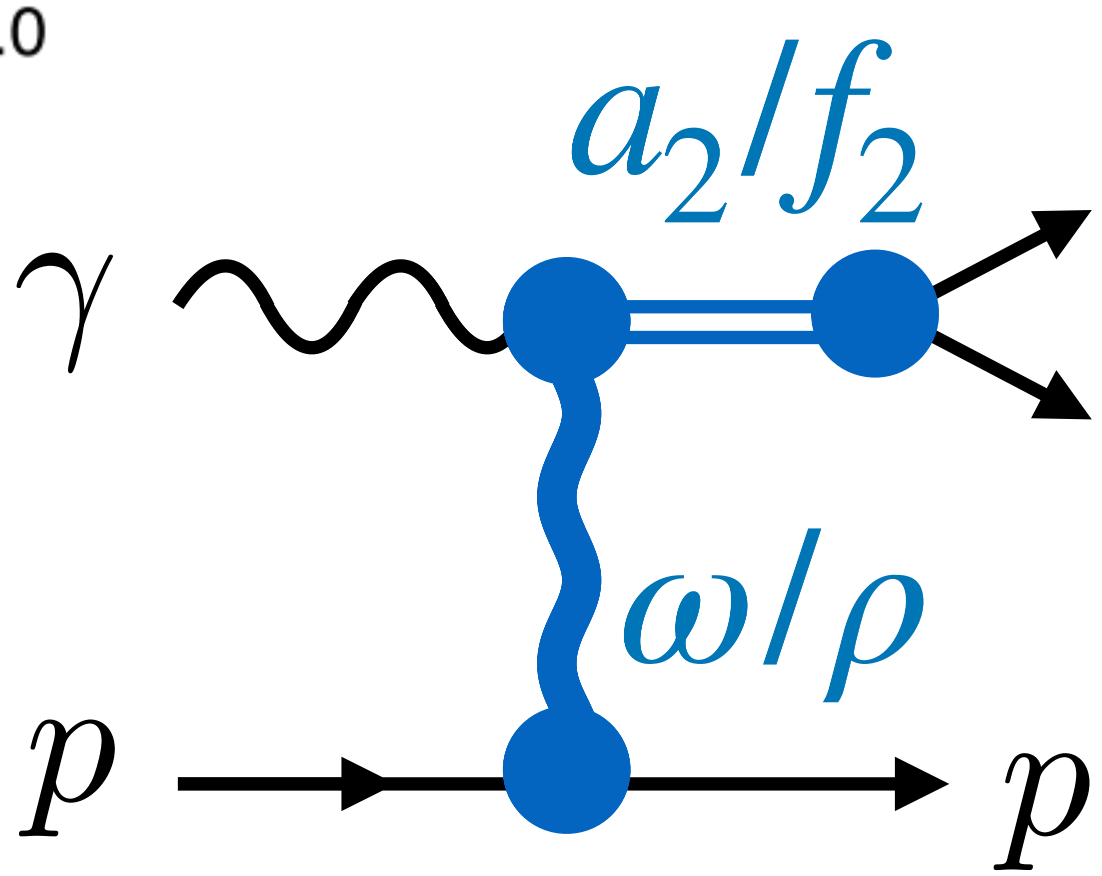


CLAS PRL126 (2021)



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

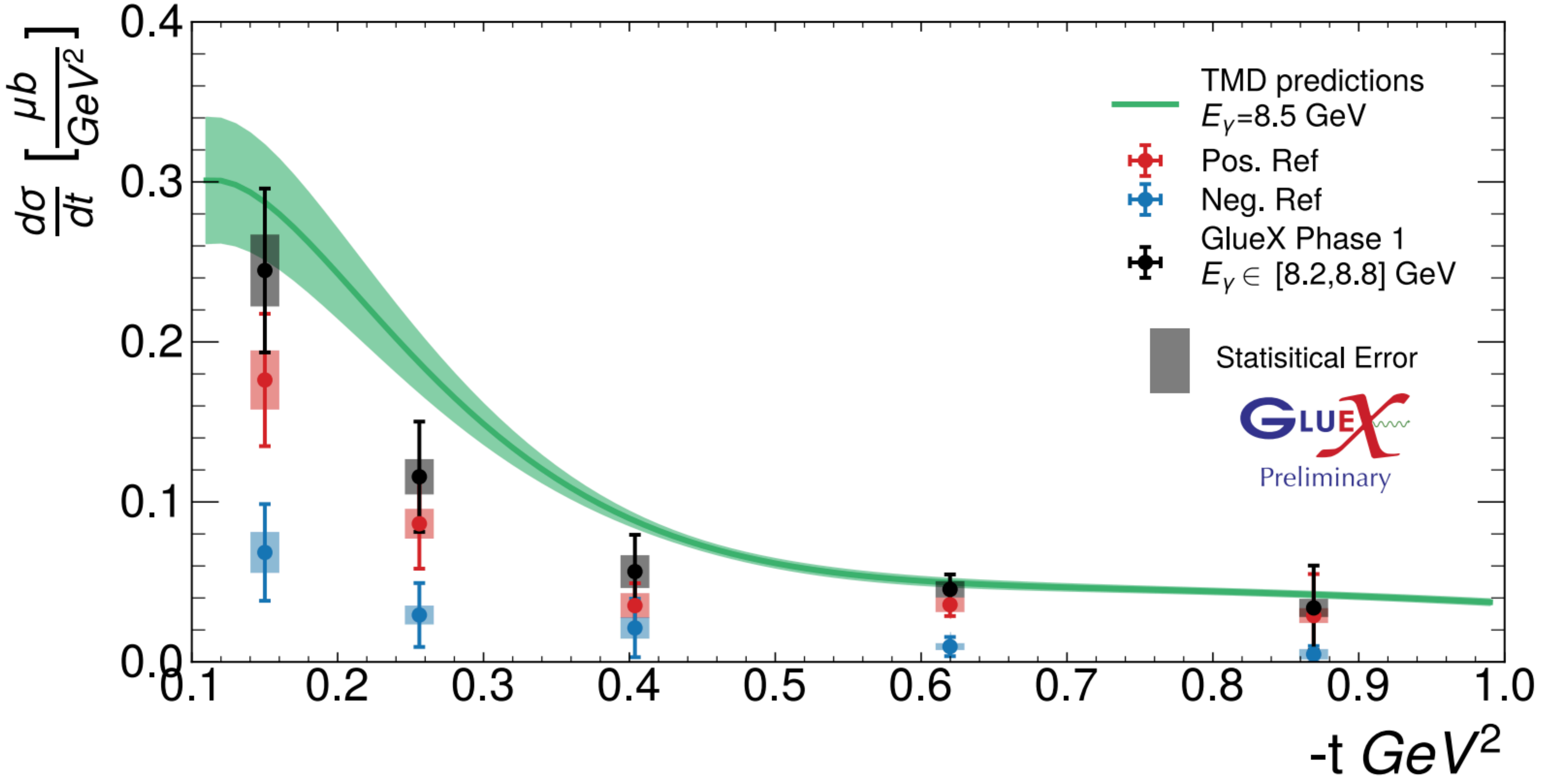
$$\omega + \frac{1}{3}\rho$$



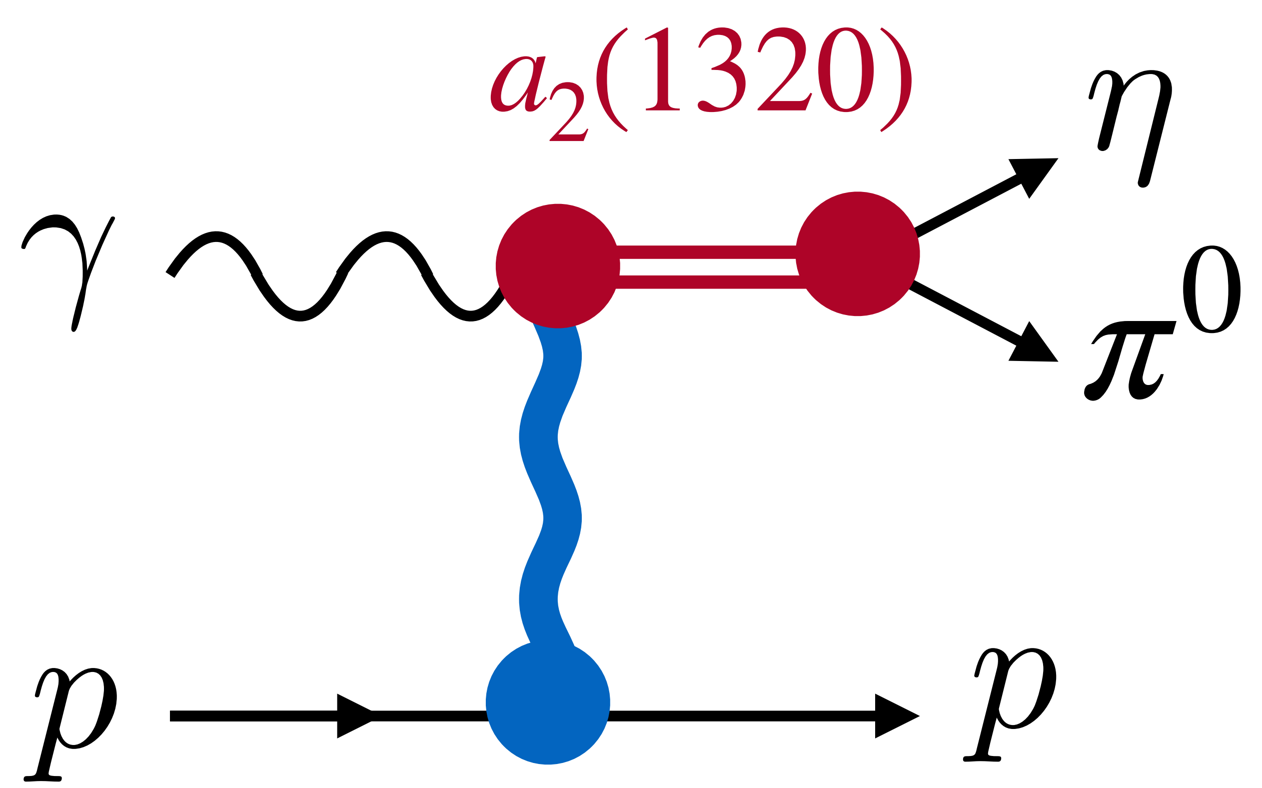
$$\gamma p \to f_2(1270)p :$$

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

Tensor Meson Photoproduction @GLueX



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



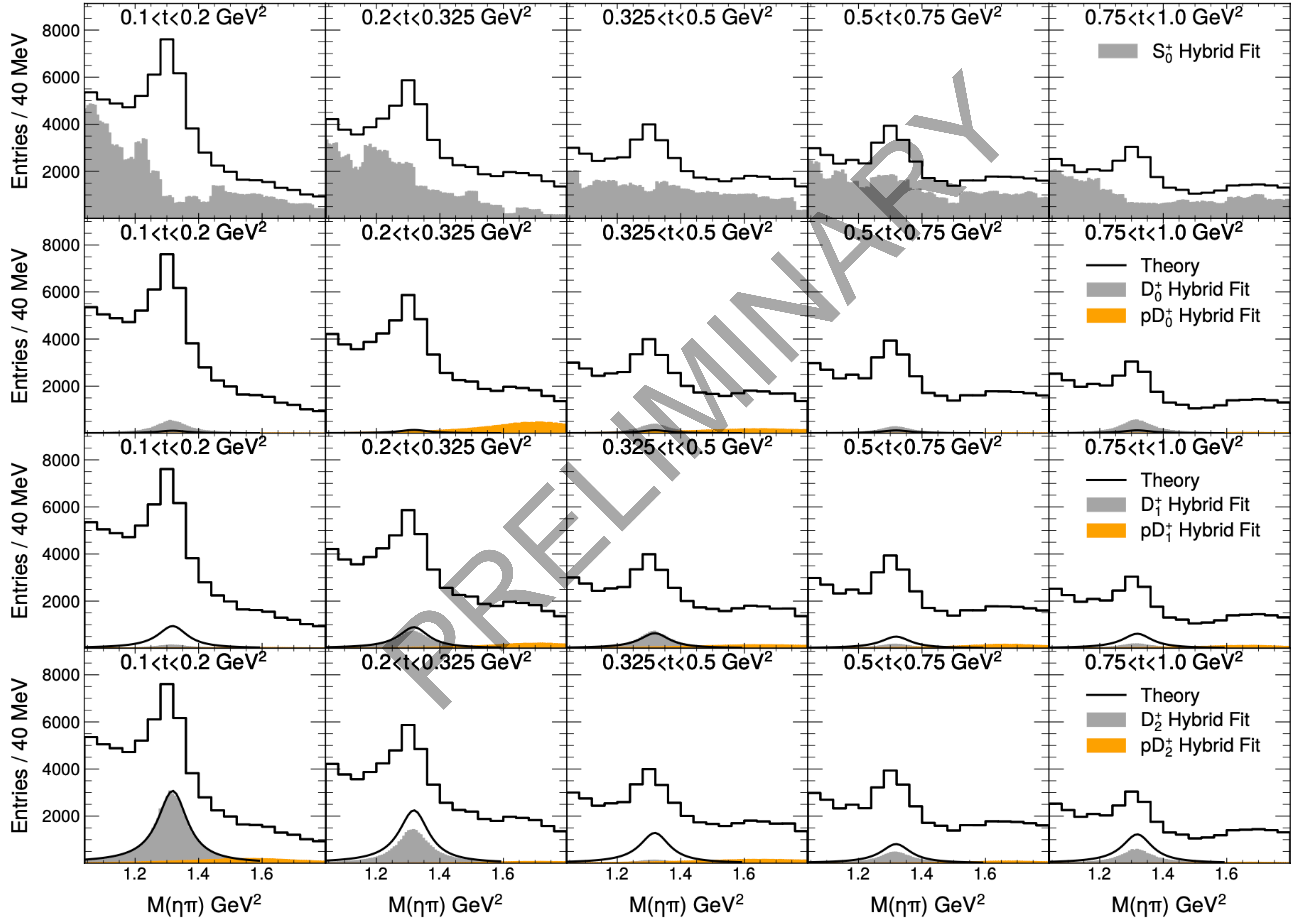
Extraction of the cross-section

Extraction of all D-waves components

Production can occur via exchange of

- vector meson (positive reflectivity) or
- axial-vector meson (negative reflectivity)

$a_2(1320)$ Photoproduction @GlueX



Extraction of $a_2(1320)$ production amplitudes from GlueX data

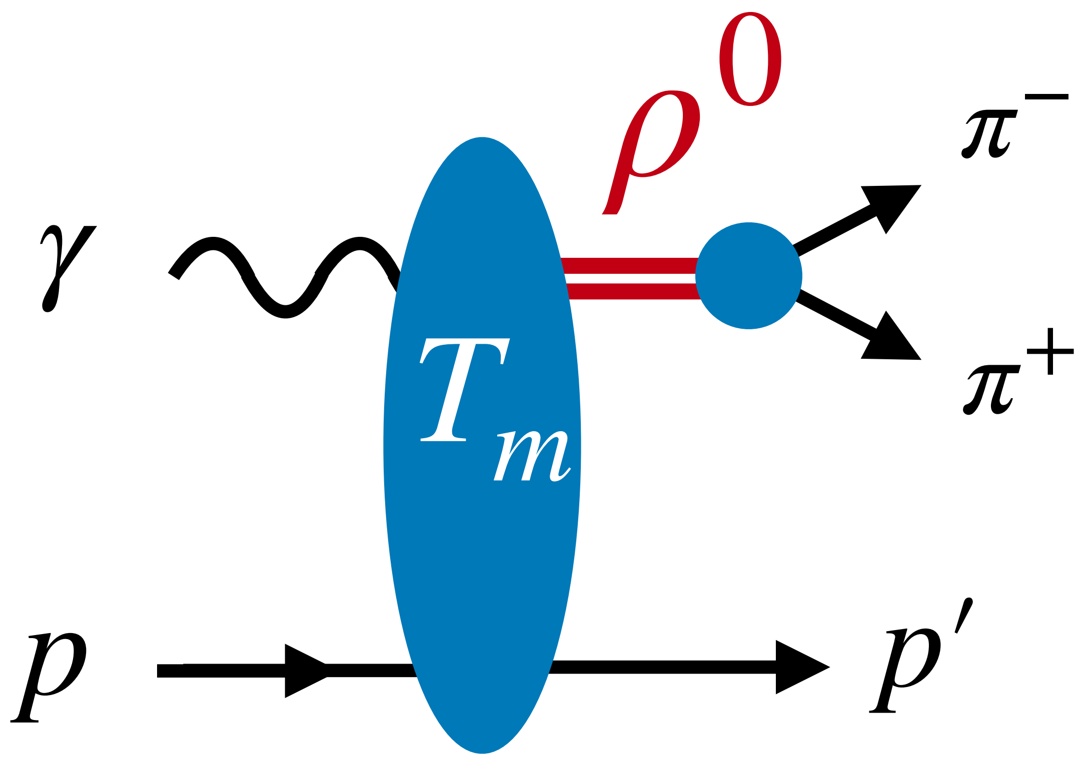
Collaboration between GlueX and JPAC

Reasonable agreement with model predictions from VM et al (JPAC) PRD102 (2020)

To appear soon…

$\rho(770)$ Photoproduction @GlueX

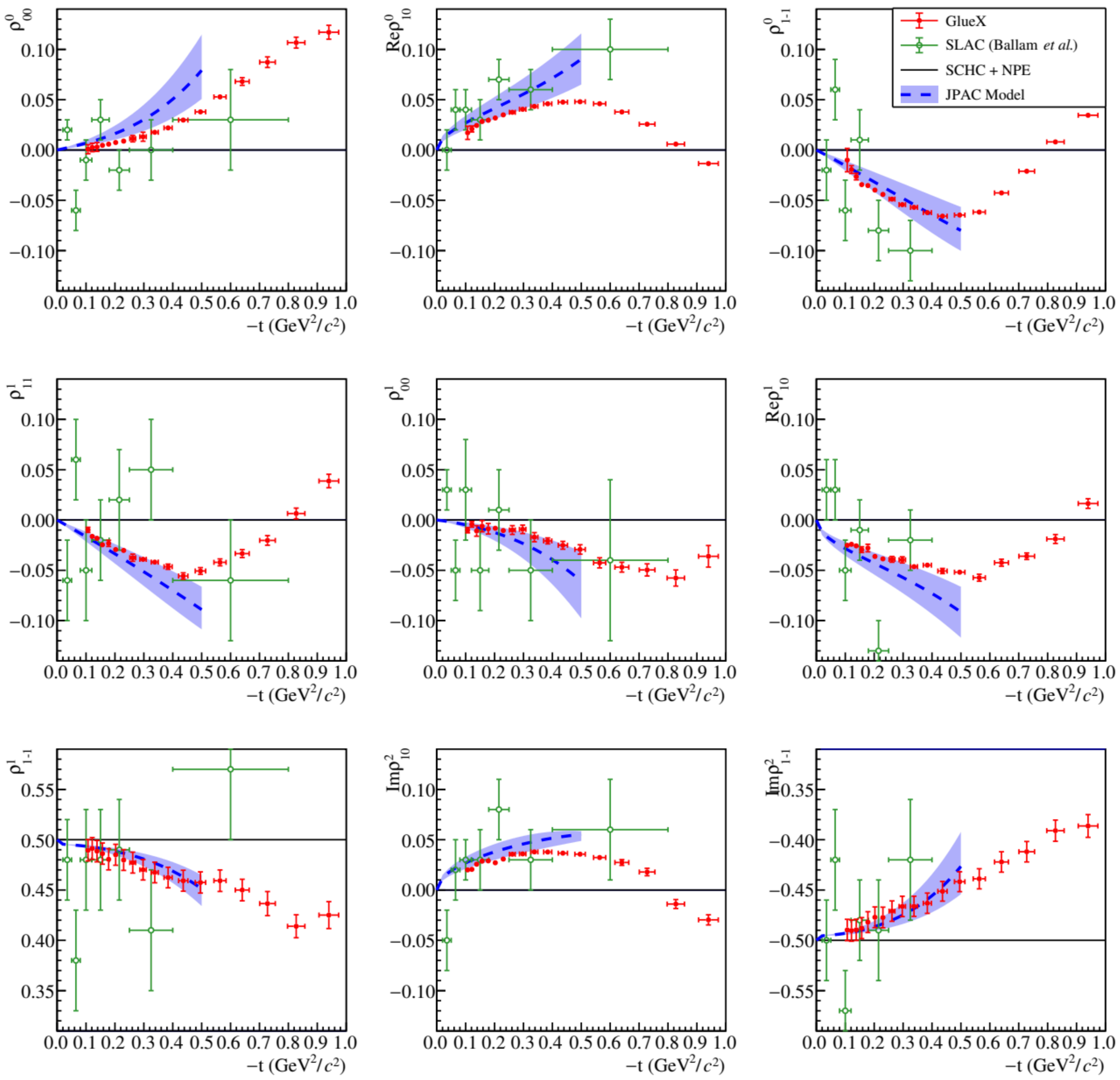
Data: GlueX, *PRC*108 (2023)
Model: JPAC, *PRD97* (2018)



$$\rho^0_{mm'} \sim T_m T^*_{m'}$$

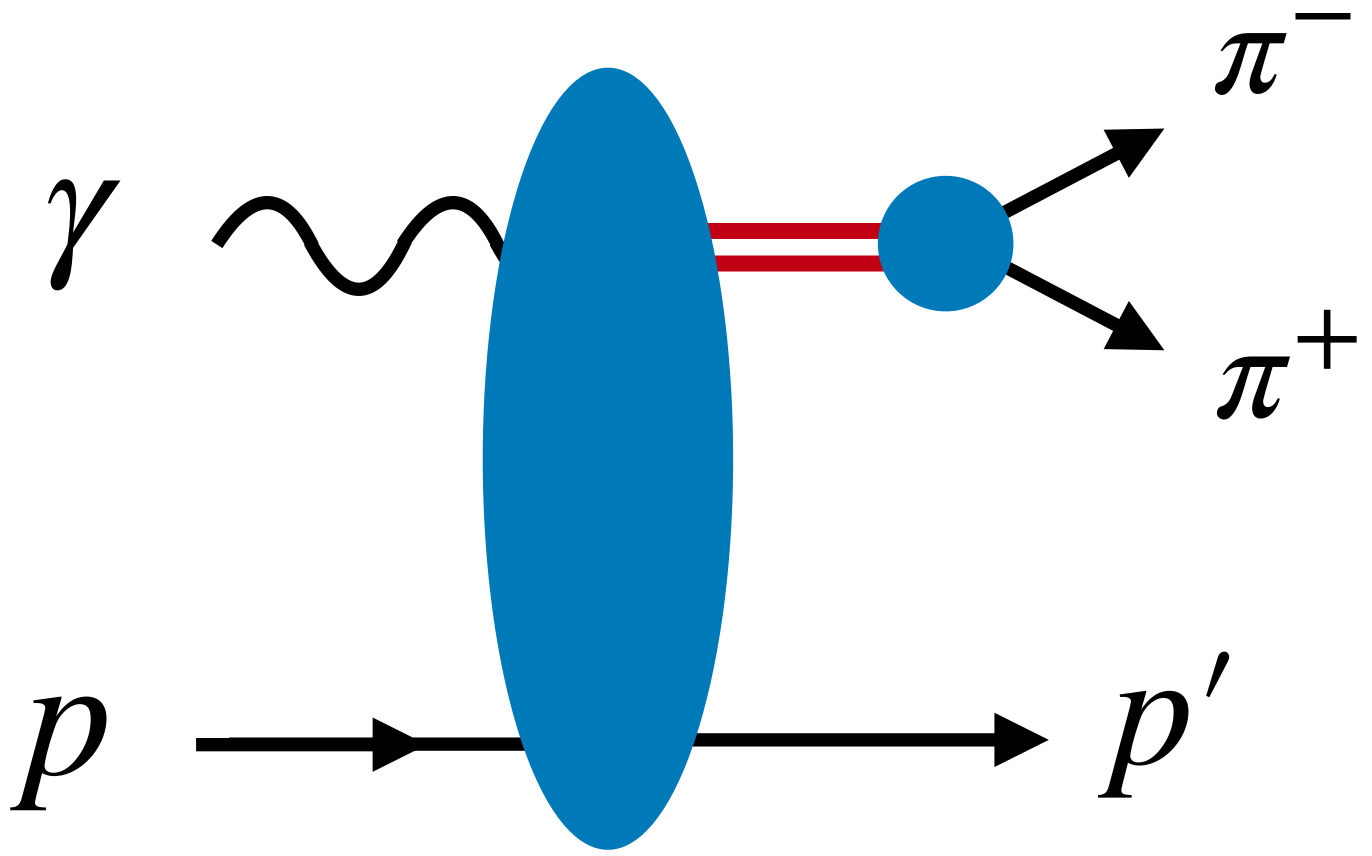
$$I(\Omega,\Phi) = I^0(\Omega) - P_\gamma \cos 2\Phi I^1(\Omega) - P_\gamma \sin 2\Phi I^2(\Omega)$$

$$\begin{aligned}
I^0(\Omega) &= \frac{3}{4\pi}\left(\frac{1}{2}(1-\rho^0_{00}) + \frac{1}{2}(3\rho^0_{00}-1)\cos^2\vartheta\right.\\
&\left. - \sqrt{2}\mathrm{Re}\rho^0_{10}\sin 2\vartheta\cos\varphi - \rho^0_{1-1}\sin^2\vartheta\cos 2\varphi\right)\\
I^1(\Omega) &= \frac{3}{4\pi}\left(\rho^1_{11}\sin^2\vartheta + \rho^1_{00}\cos^2\vartheta\right.\\
&\left. - \sqrt{2}\mathrm{Re}\rho^1_{10}\sin 2\vartheta\cos\varphi - \rho^1_{1-1}\sin^2\vartheta\cos 2\varphi\right)\\
I^2(\Omega) &= \frac{3}{4\pi}\left(\sqrt{2}\mathrm{Im}\rho^2_{10}\sin 2\vartheta\sin\varphi\right.\\
&\left. + \mathrm{Im}\rho^2_{1-1}\sin^2\vartheta\sin 2\varphi\right).
\end{aligned}$$



Moment Expansion

Five independent variables: $s, t, m, \Omega = (\theta, \phi)$

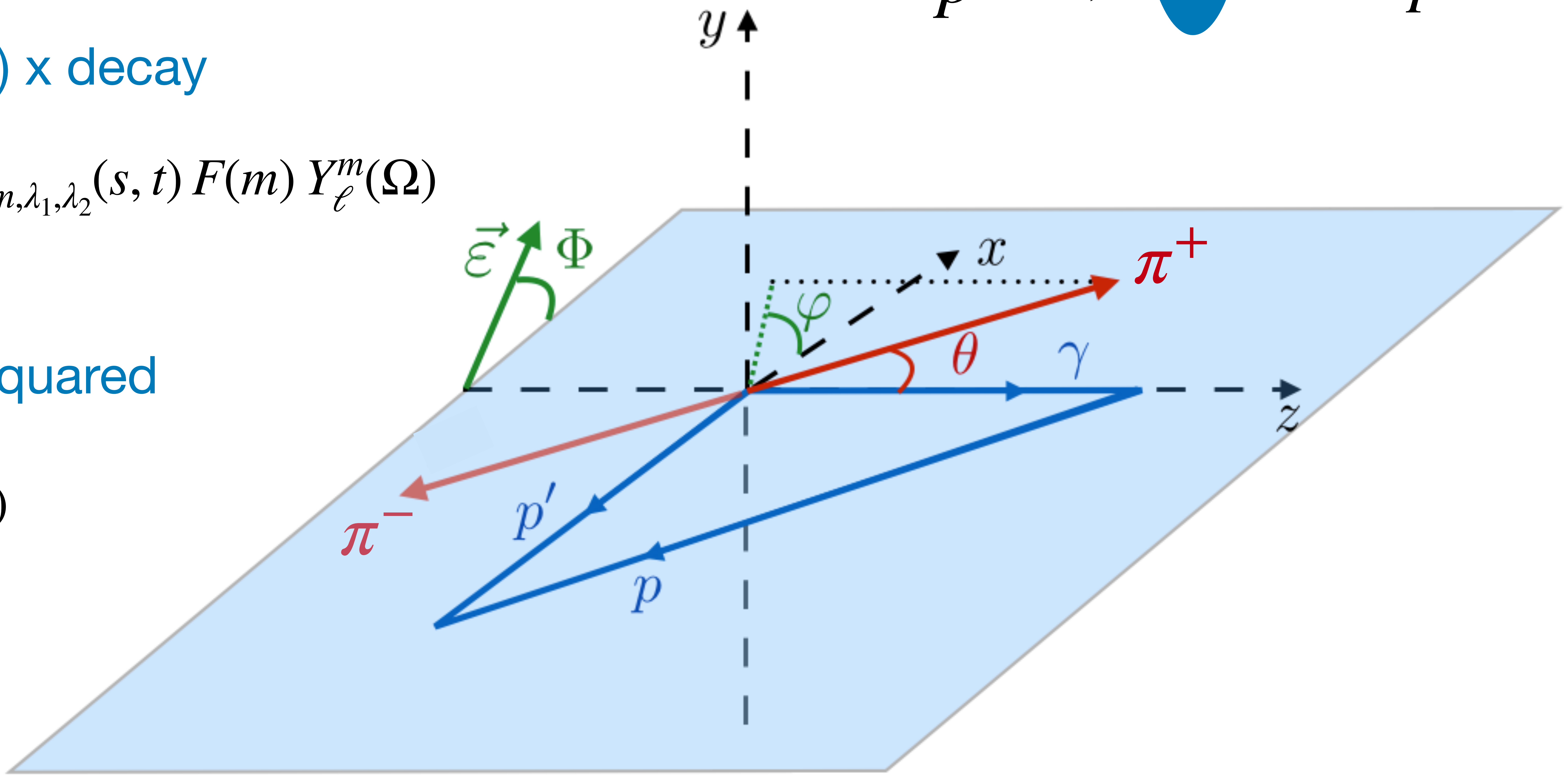


(Production amplitudes) x decay

$$A_{\lambda,\lambda_1,\lambda_2}(s,t,m,\Omega) = \sum_{\ell,m} T_{\lambda,m,\lambda_1,\lambda_2}(s,t)\, F(m)\, Y_\ell^m(\Omega)$$

Intensity is amplitude squared

$$I(\Omega) = \sum_{L,M} H^0(LM)\ Y_\ell^m(\Omega)$$



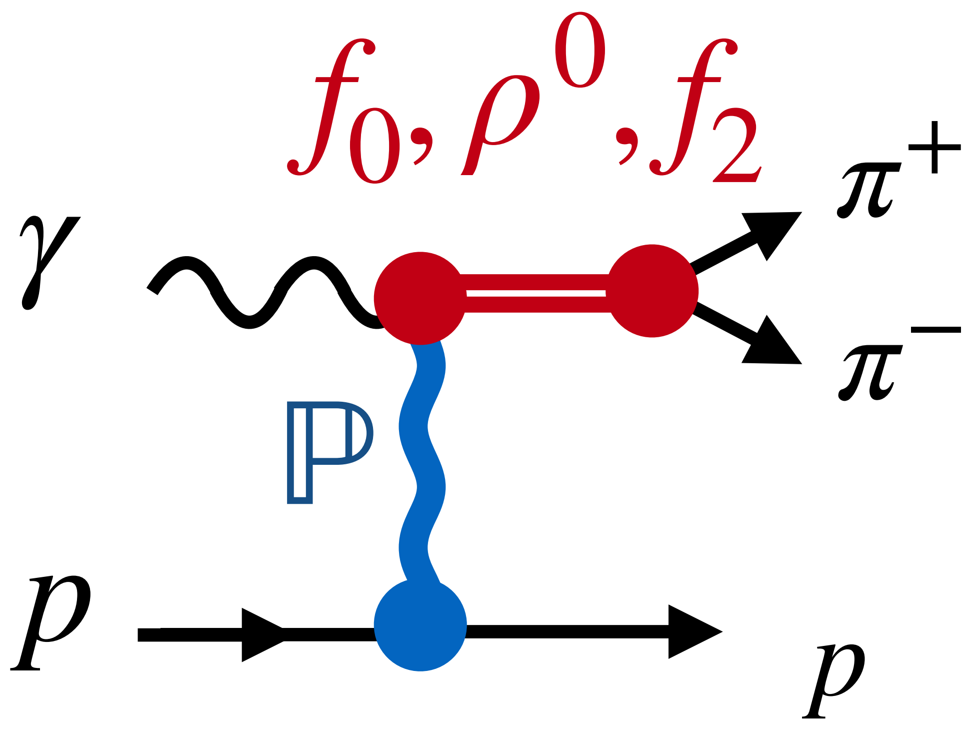
Moment Expansion

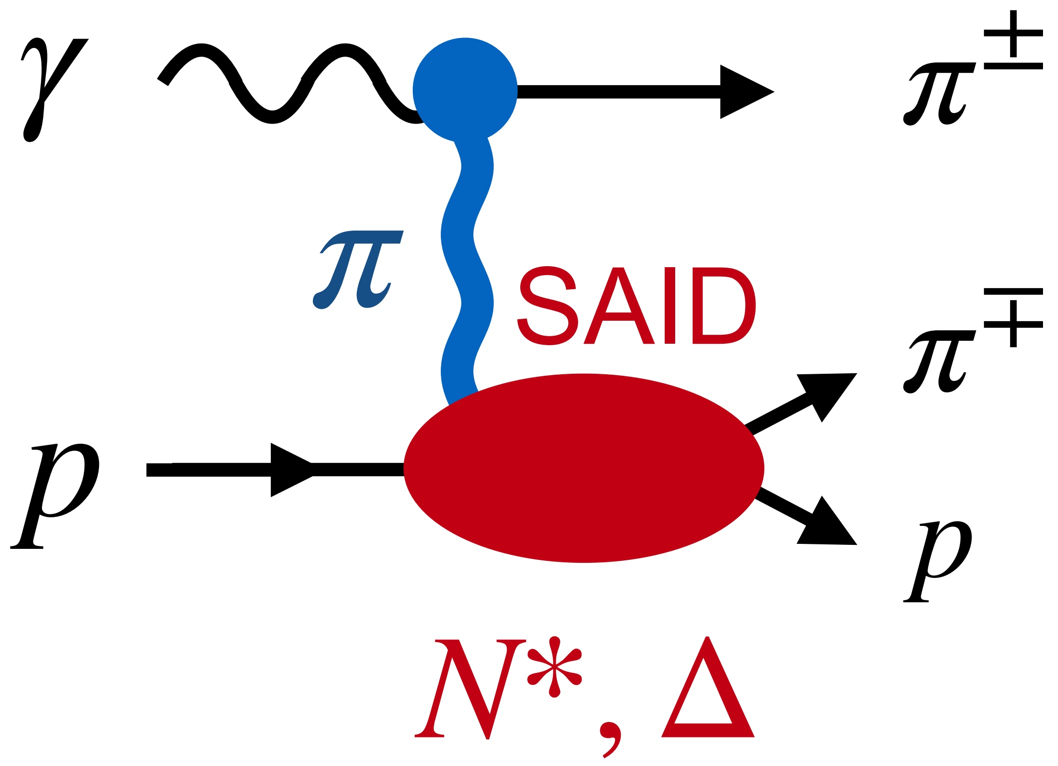
Five independent variables: $s, t, m, \Omega = (\theta, \phi)$

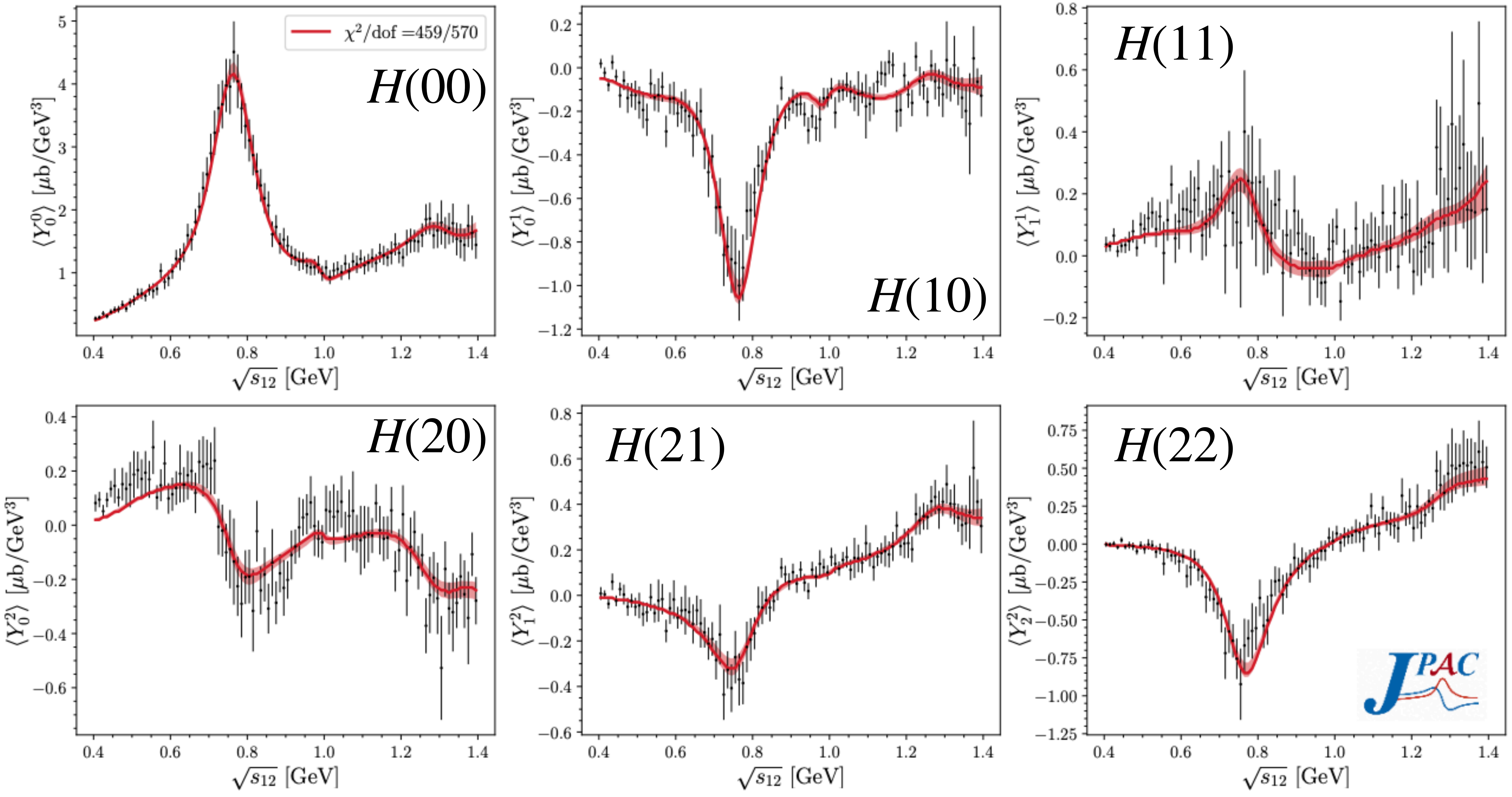
$E_\gamma = 3.4$ GeV and $t = -0.95$ GeV^2

Data: CLAS, PRD80 (2009) 072005

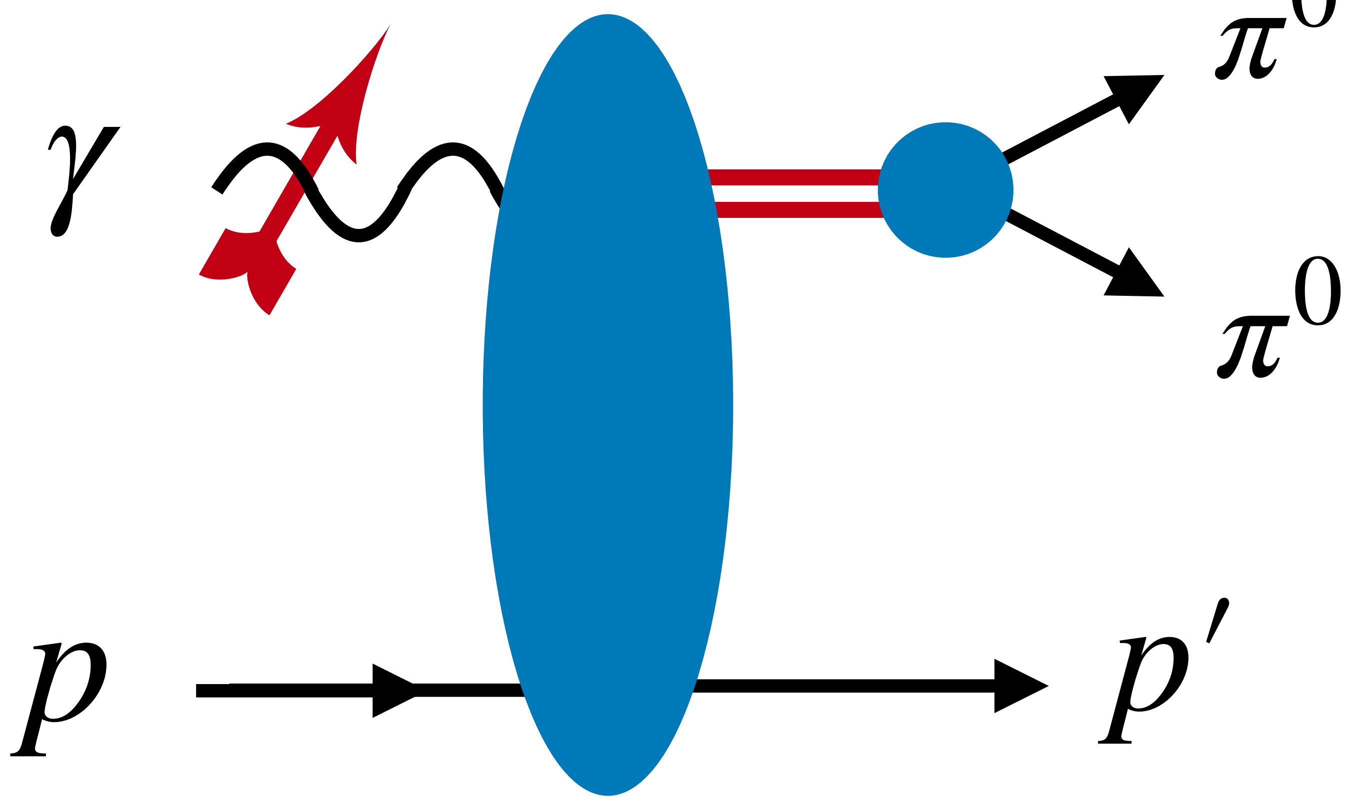
Model: JPAC, arXiv:2406.08016







Polarized Moment Expansion

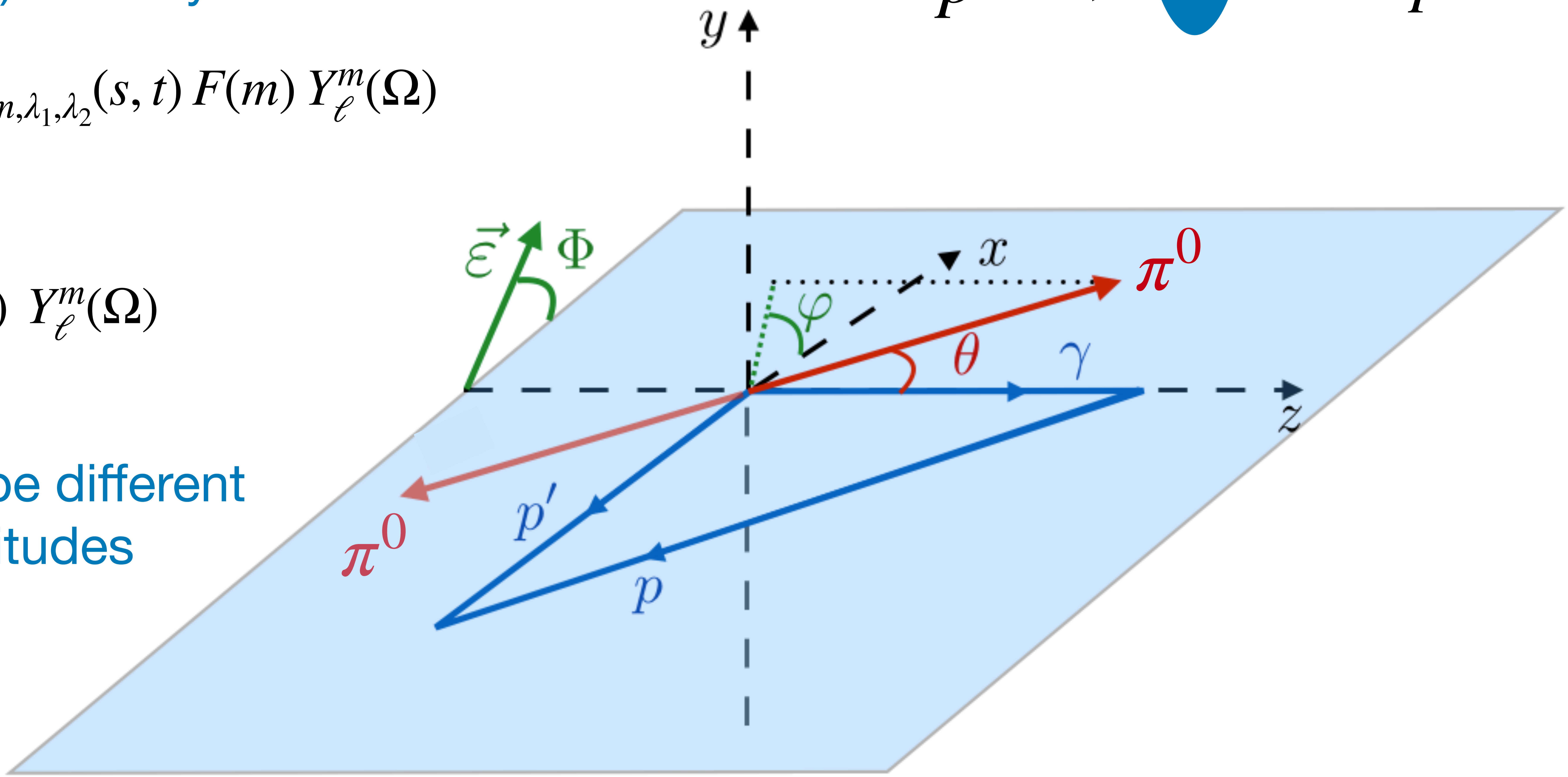


$$I(\Omega, \Phi) = I^0(\Omega) - P_\gamma \cos 2\Phi \; I^1(\Omega) - P_\gamma \sin 2\Phi \; I^2(\Omega)$$

(Production amplitudes) x decay

$$A_{\lambda,\lambda_1,\lambda_2}(s,t,m,\Omega) = \sum_{\ell,m} T_{\lambda,m,\lambda_1,\lambda_2}(s,t)\, F(m)\, Y_\ell^m(\Omega)$$

$$I^{0,1,2}(\Omega) = \sum_{L,M} H^{0,1,2}(LM)\;\; Y_\ell^m(\Omega)$$

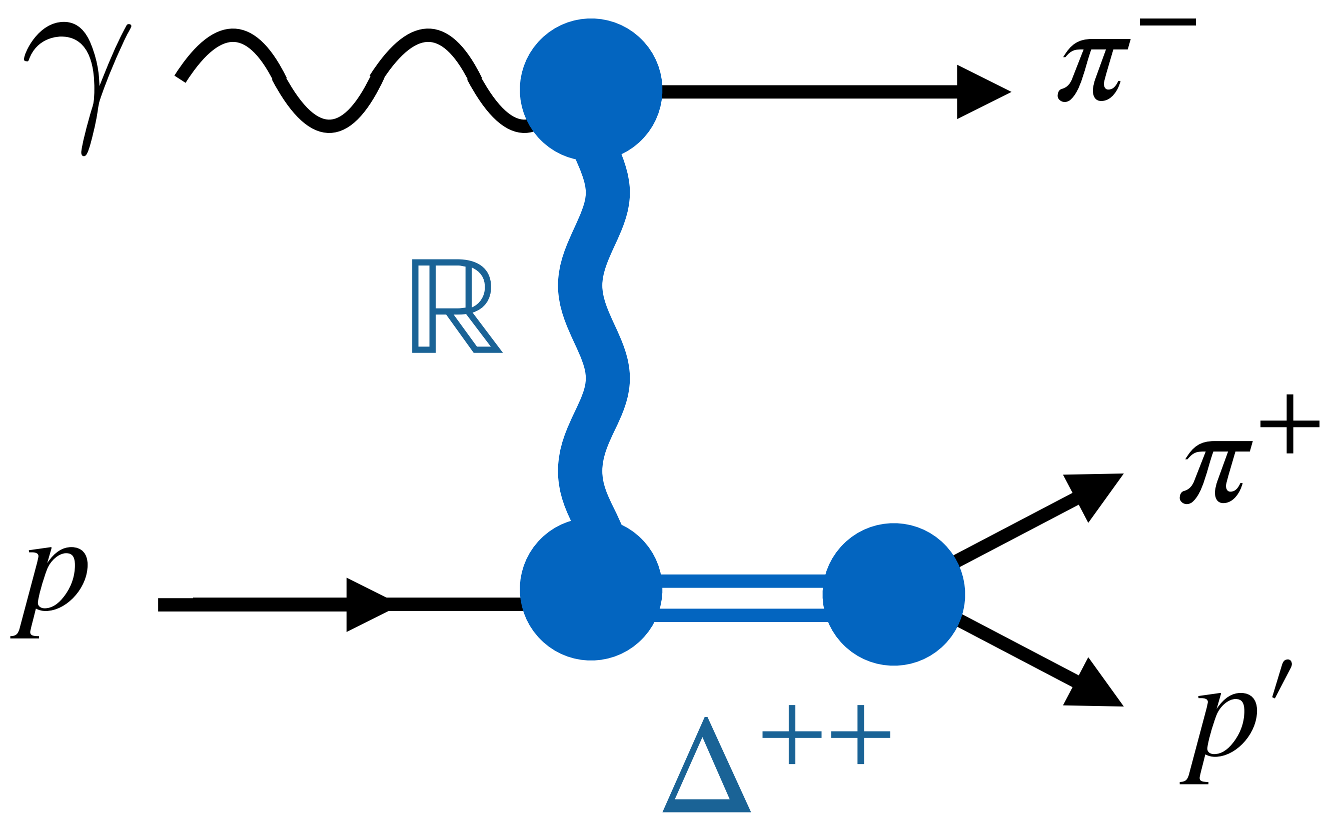


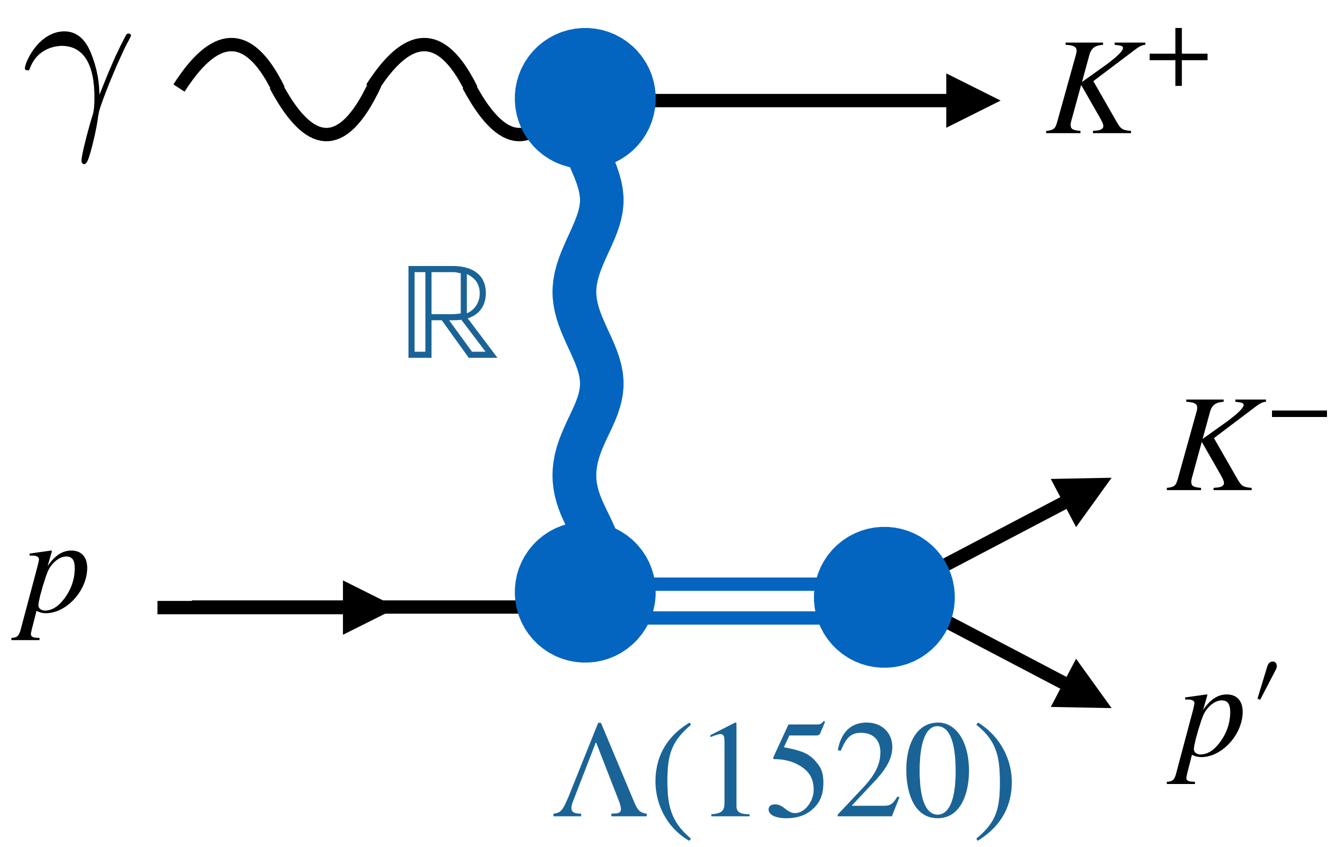
Different moments probe different quadratic form of amplitudes

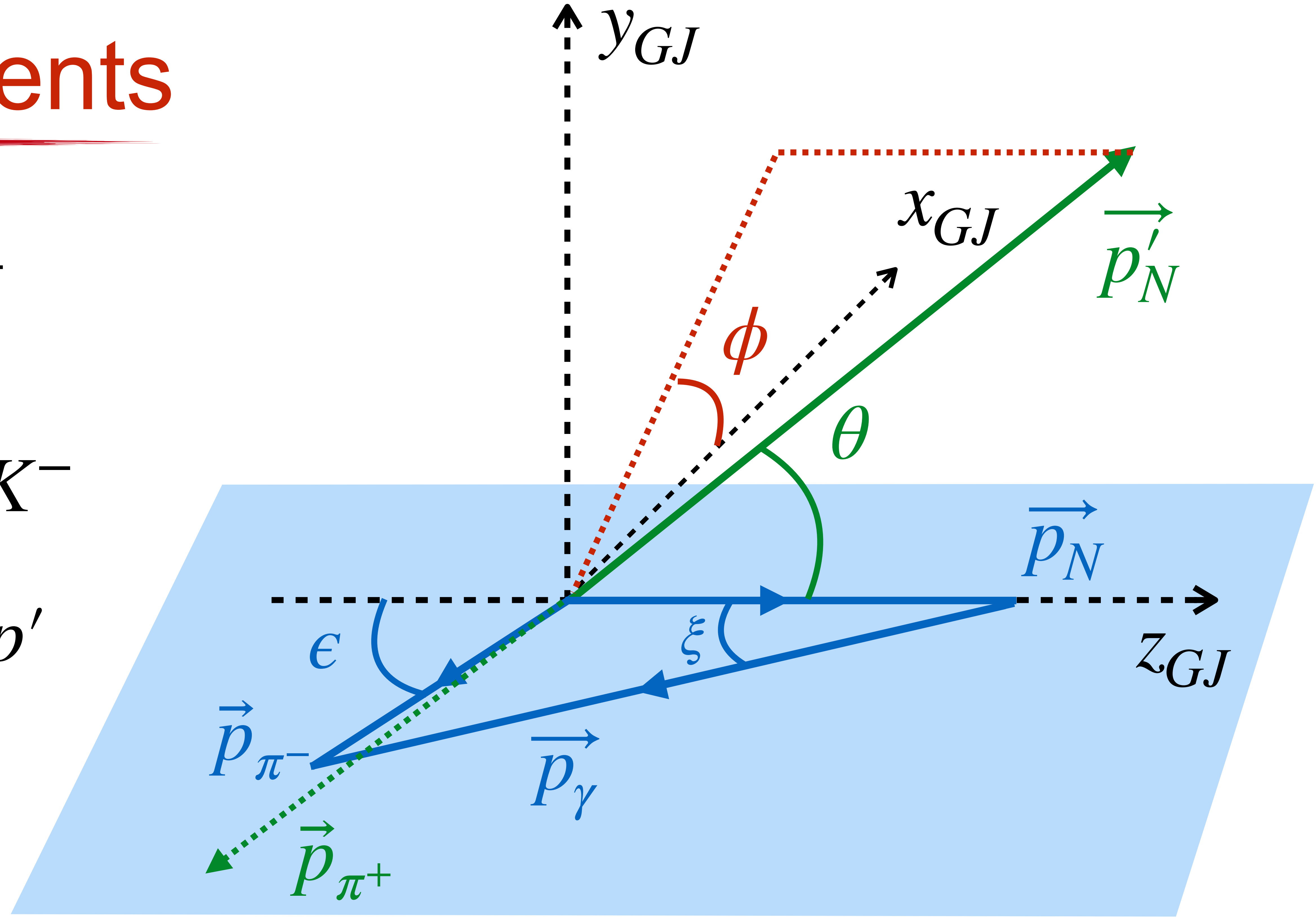
Polarized Moment Expansion

From A. Thiel (GlueX data)

Polarized Spin Density Matrix Elements



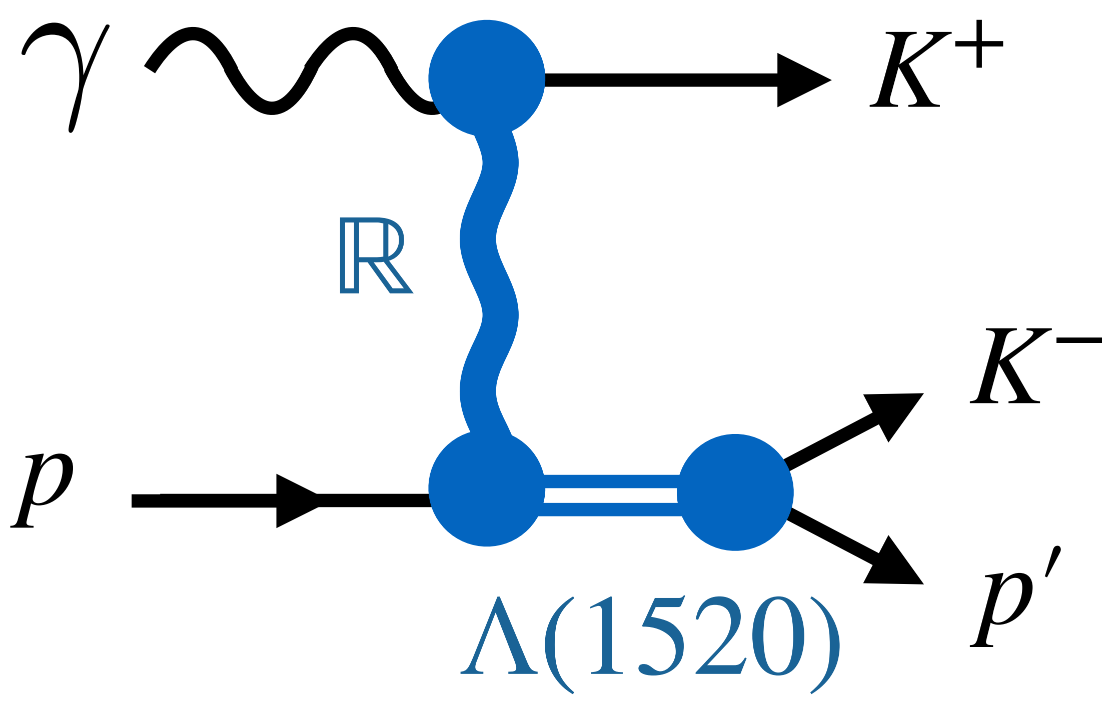




Access to 9 SDME with linear beam polarization

$$W(\theta,\phi,\Phi) = \frac{1}{2\pi}\frac{d\sigma}{dt}\frac{3}{4\pi}\left\{\rho^0_{33}\sin^2\theta + \rho^0_{11}\left(\frac{1}{3}+\cos^2\theta\right) - \frac{2}{\sqrt{3}}\mathrm{Re}\rho^0_{31}\sin 2\theta\cos\phi - \frac{2}{\sqrt{3}}\mathrm{Re}\rho^0_{3-1}\sin^2\theta\cos 2\phi\right.$$
$$-P_\gamma\cos 2\Phi\left[\rho^1_{33}\sin^2\theta + \rho^1_{11}\left(\frac{1}{3}+\cos^2\theta\right) - \frac{2}{\sqrt{3}}\mathrm{Re}\rho^1_{31}\sin 2\theta\cos\phi - \frac{2}{\sqrt{3}}\mathrm{Re}\rho^1_{3-1}\sin^2\theta\cos 2\phi\right]$$
$$\left.-P_\gamma\sin 2\Phi\frac{2}{\sqrt{3}}\left[\mathrm{Im}\rho^2_{31}\sin 2\theta\sin\phi + \mathrm{Im}\rho^2_{3-1}\sin^2\theta\sin 2\phi\right]\right\}.$$

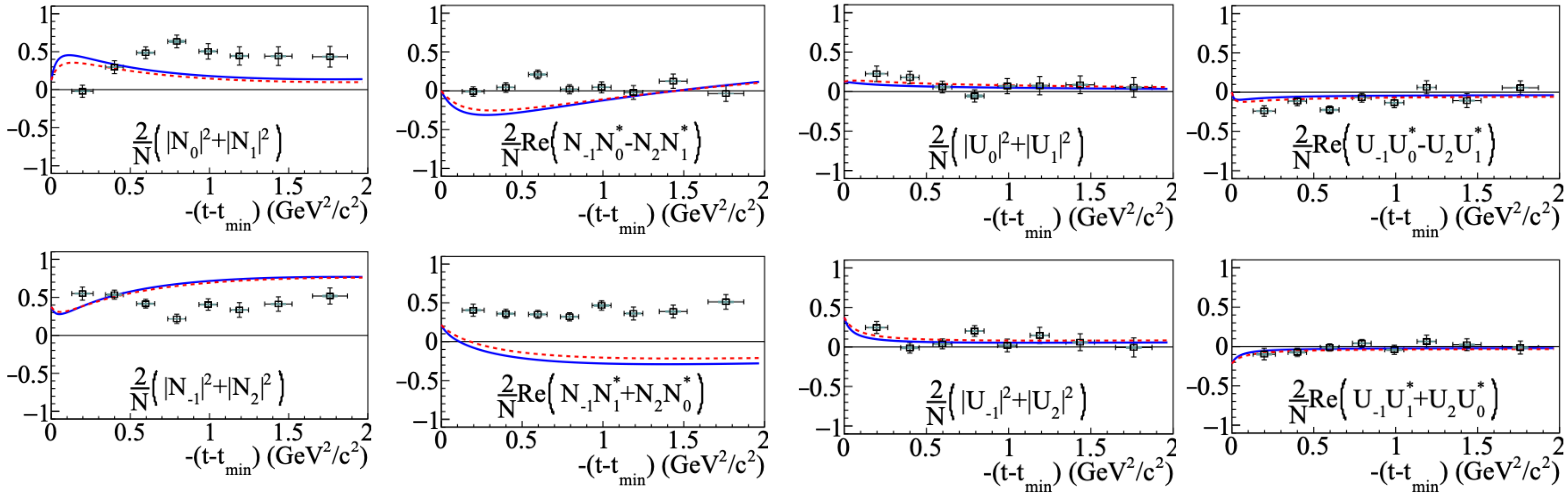
Polarized Spin Density Matrix Elements



Negative reflectivity component compatible with kaon (spin 0) exchange

Data from GlueX, PRC105 (2022)

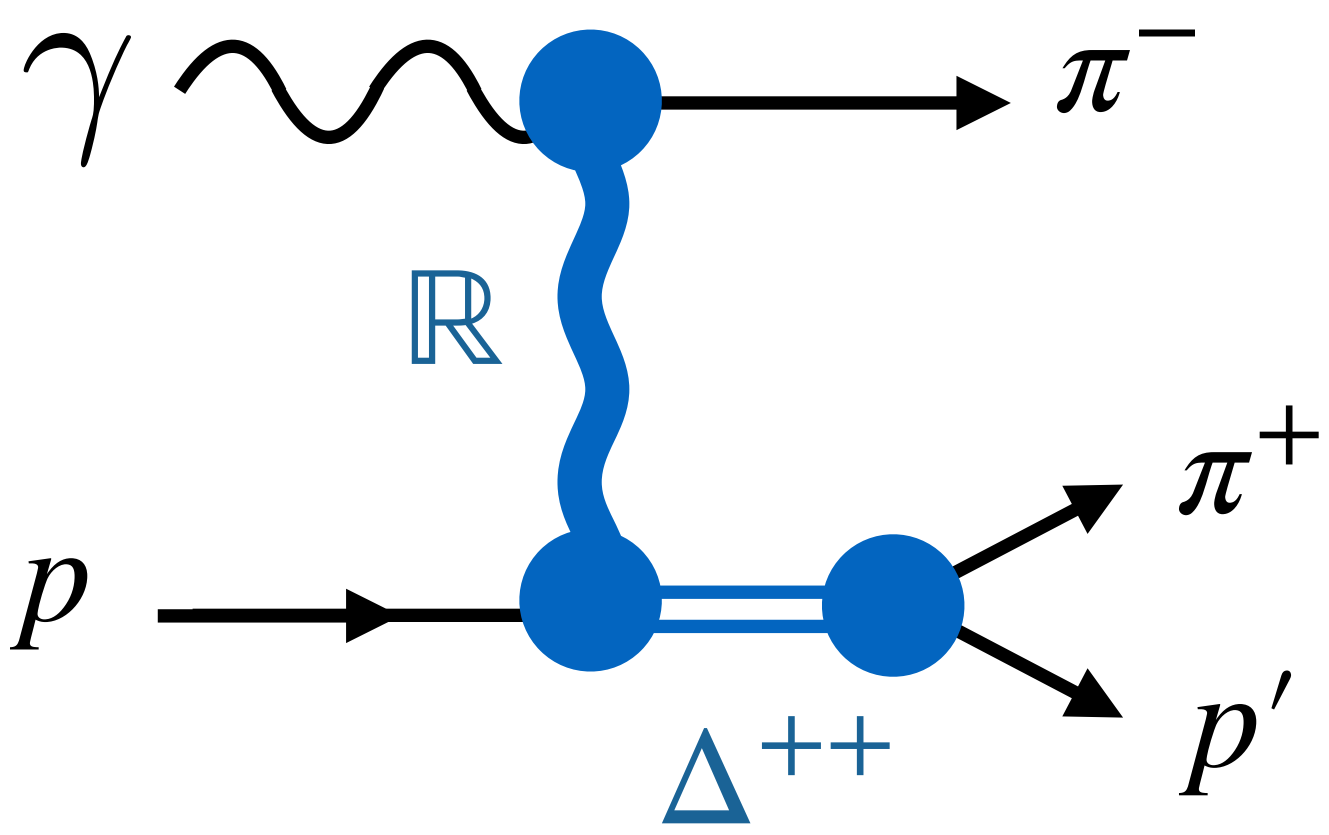
Model from Yu and Kong, PRC96, (2017)

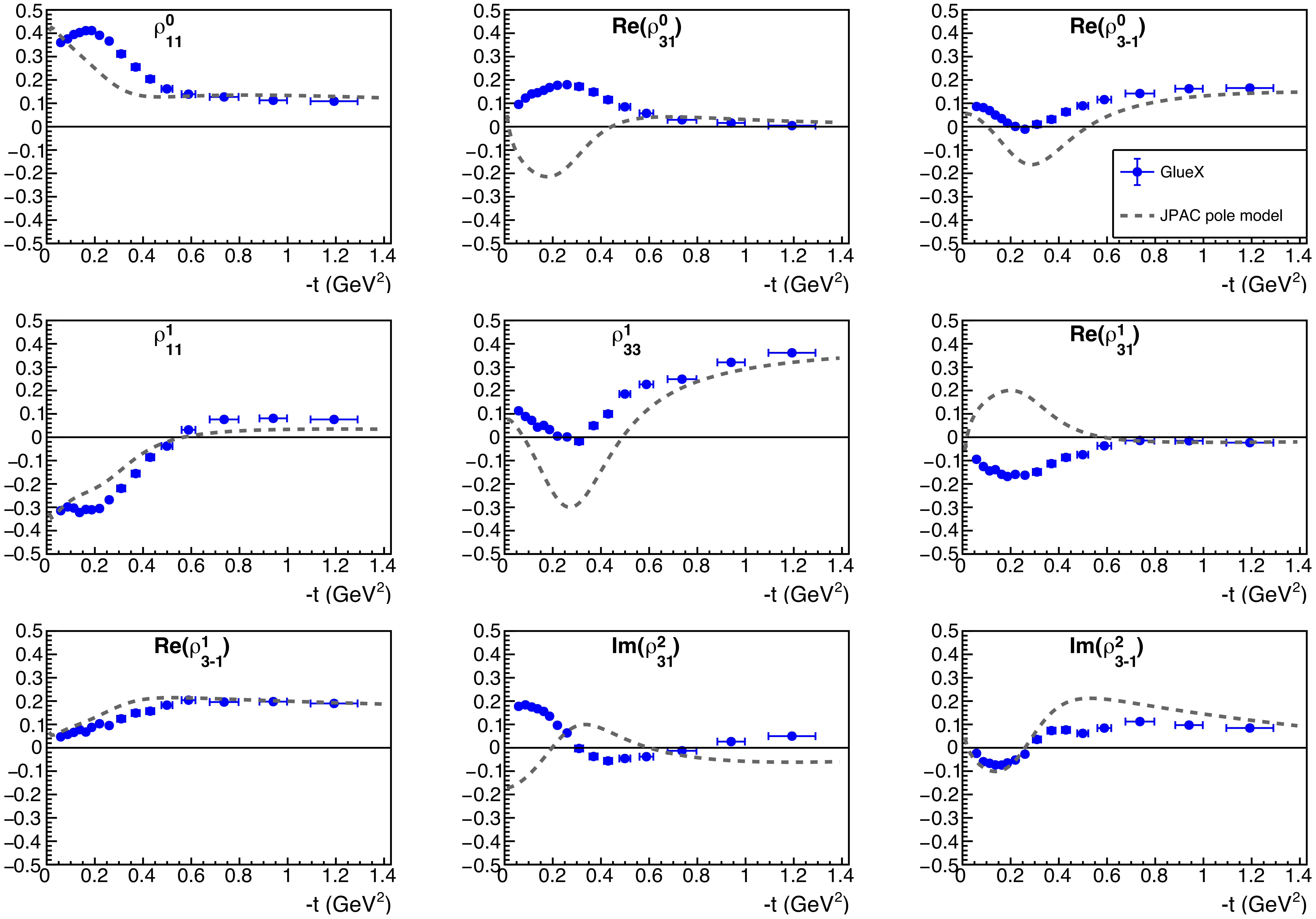


Polarized Spin Density Matrix Elements

Data from GlueX, to appear soon

Model from JPAC, PLB779 (2018)





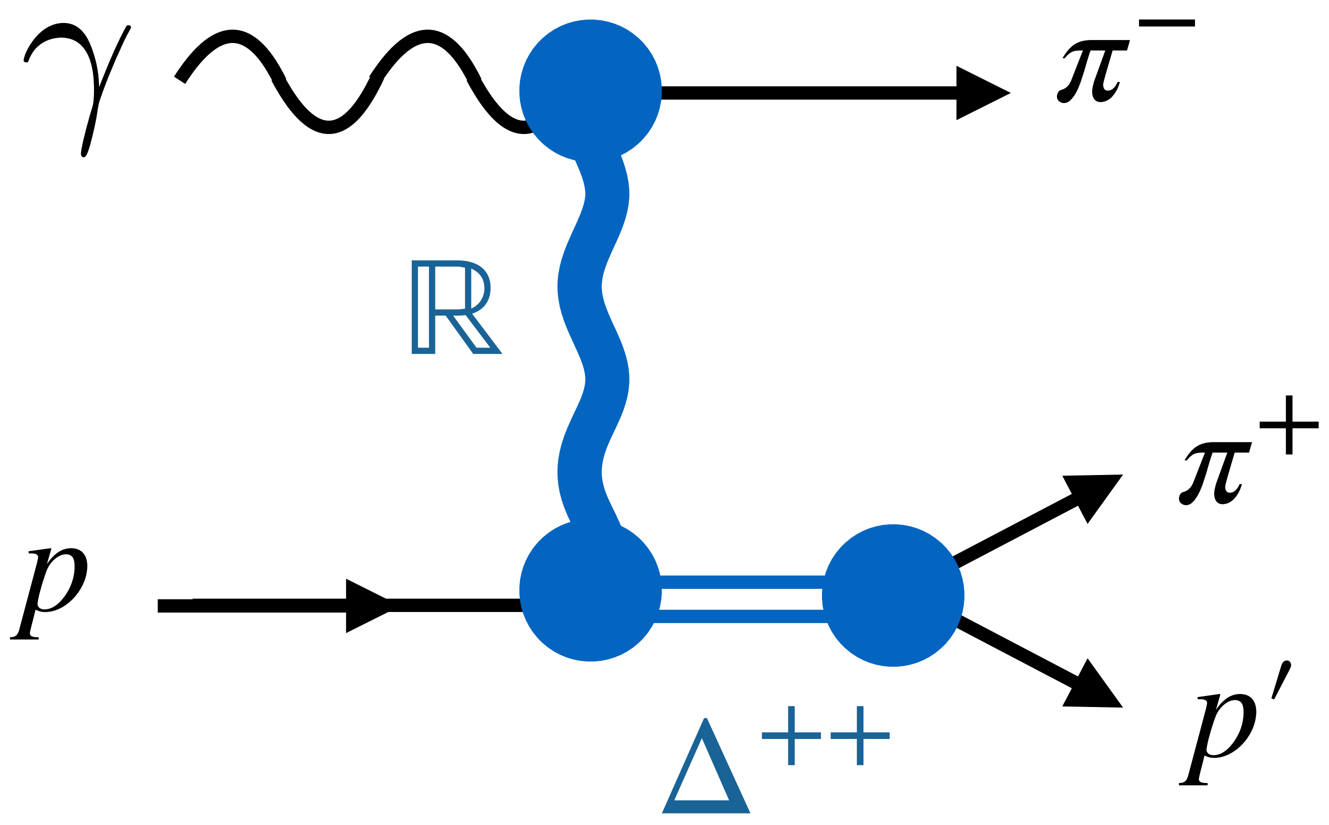
Good agreement… up to signs!

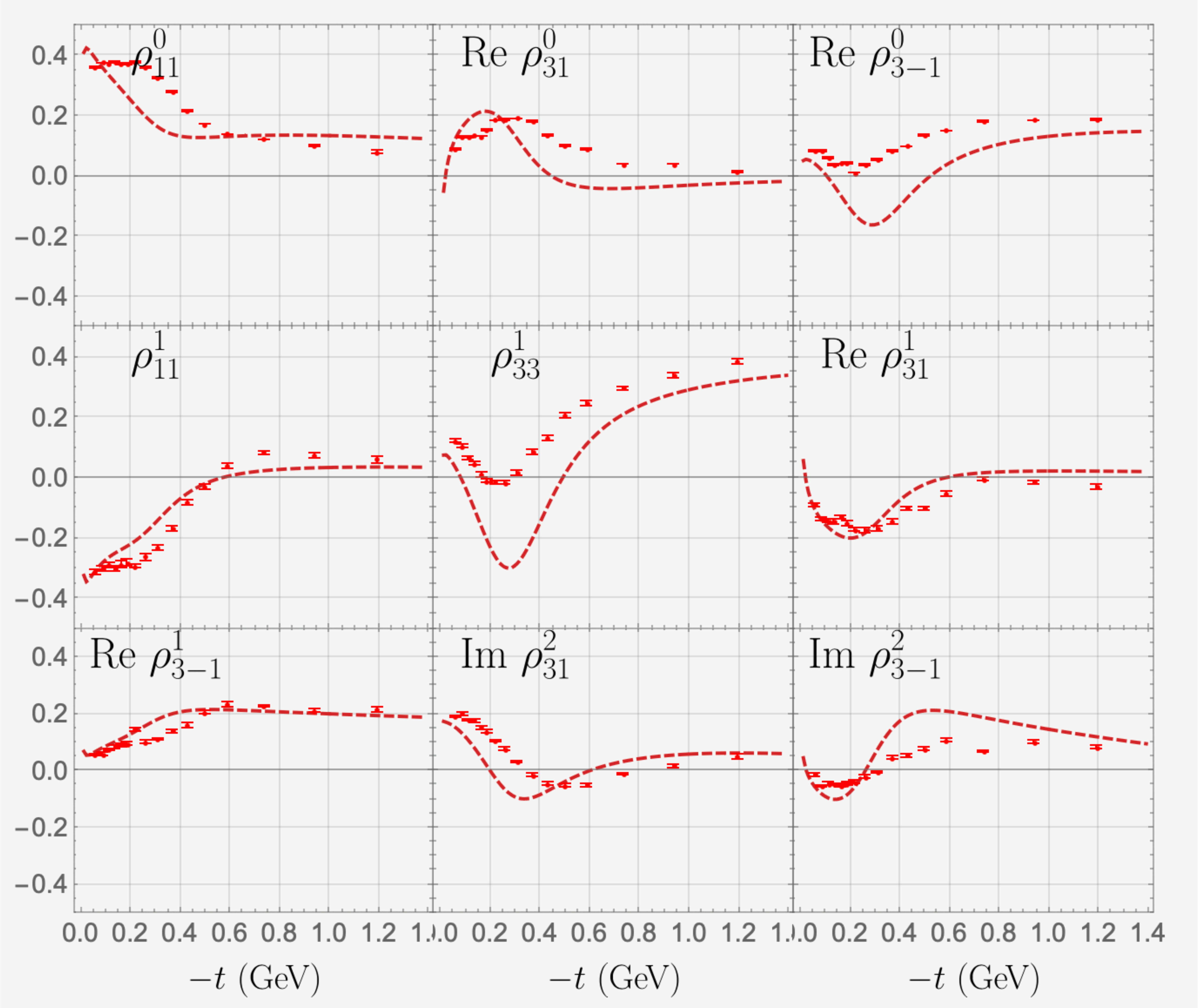
$\rho_{31}^{0,1,2}$ have opposite sign

Polarized Spin Density Matrix Elements

Data from GlueX, to appear soon

Model from JPAC, PLB779 (2018)





Change sign of

$\rho - p - \Delta$ and $b_1 - p - \Delta$ couplings

Summary

Two meson photoproduction are physics-rich reactions

If a single resonance dominates —> SDME

If not —> Moment expansion

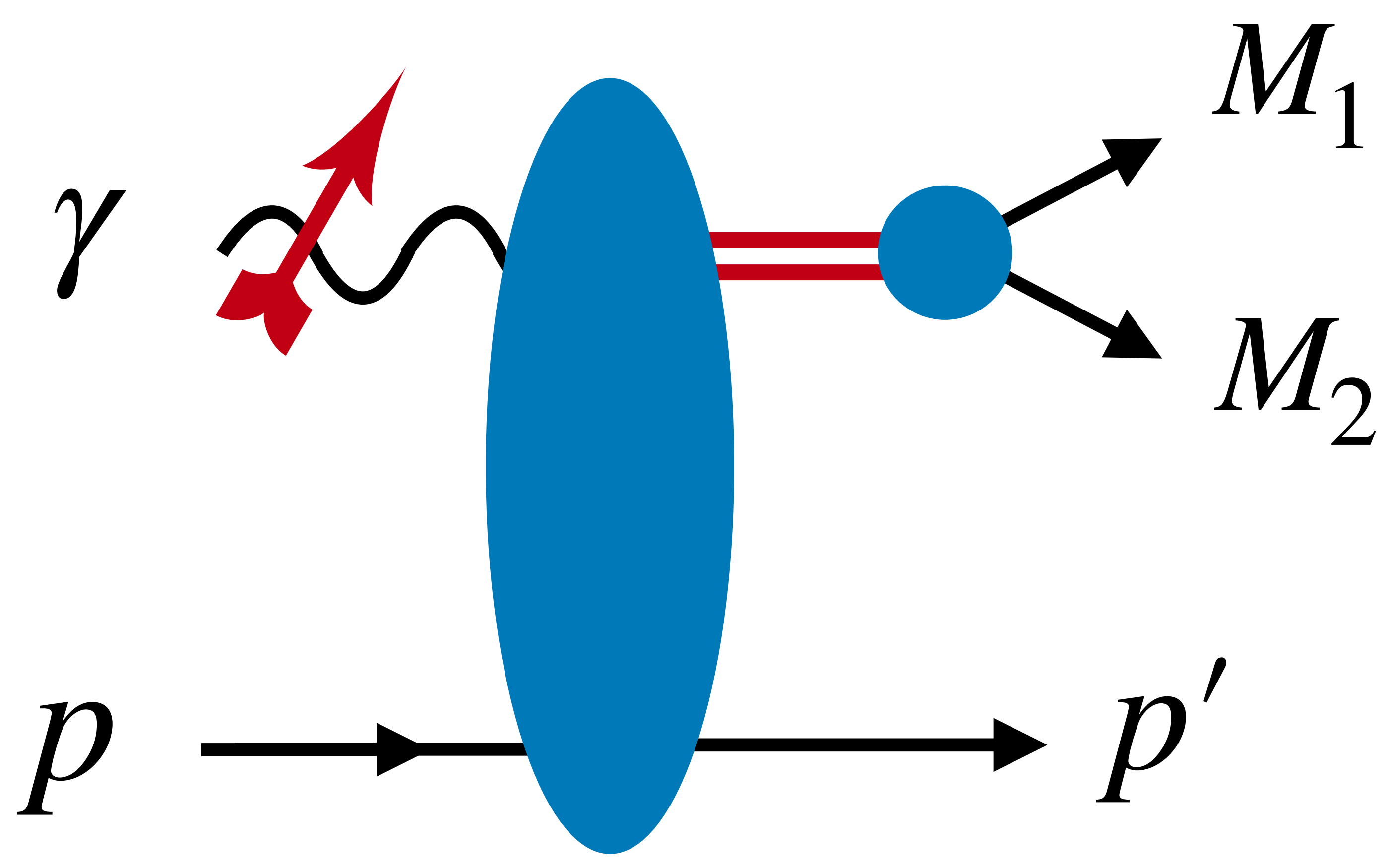
Extracting weak (exotic) signal require deep understanding of production mechanism

Need models to understand data

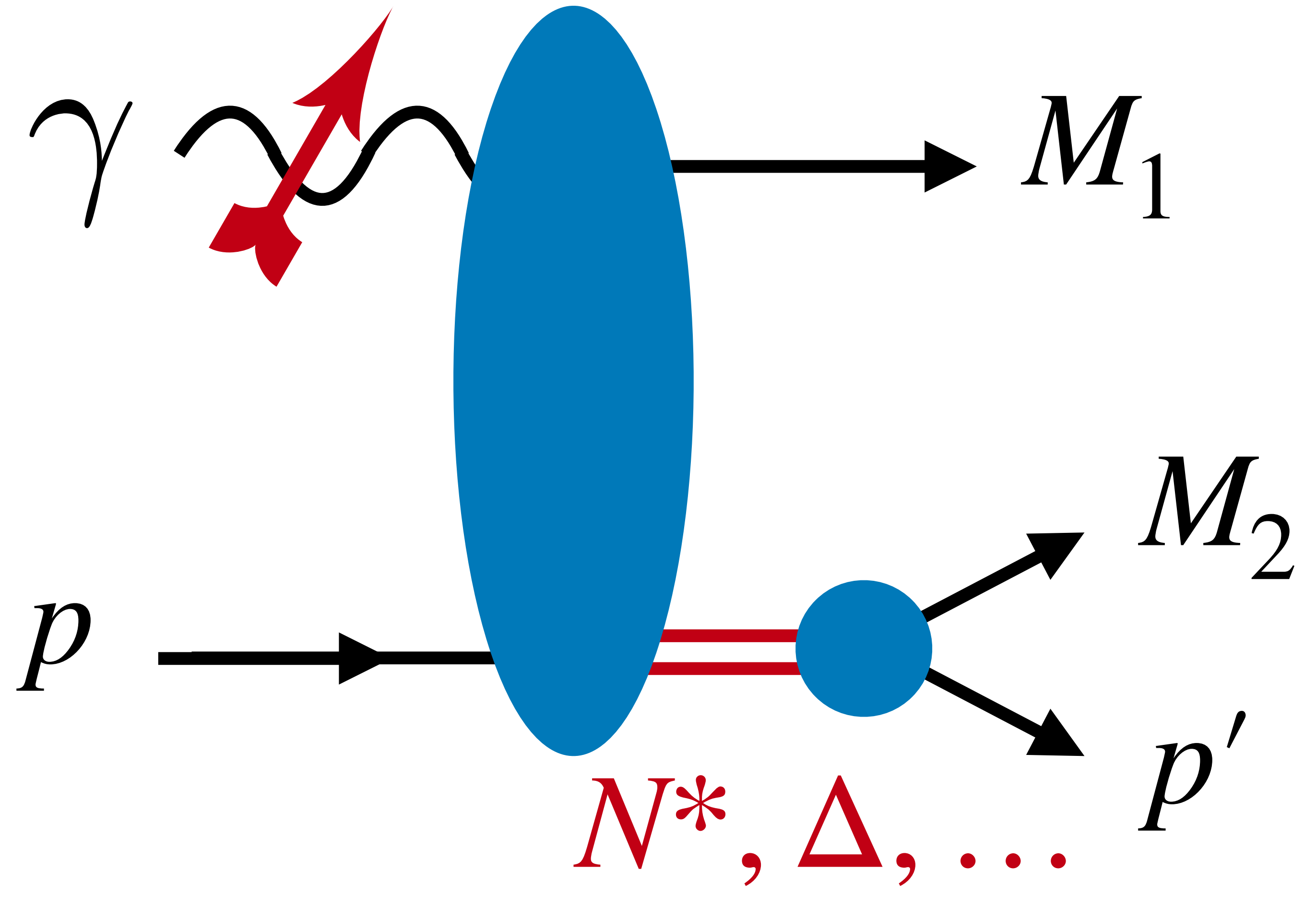
Fruitful collaboration between CLAS/GlueX and JPAC

Still of a lot work on formalism, models, data analyses,… to do

Meson spectroscopy



Baryon spectroscopy

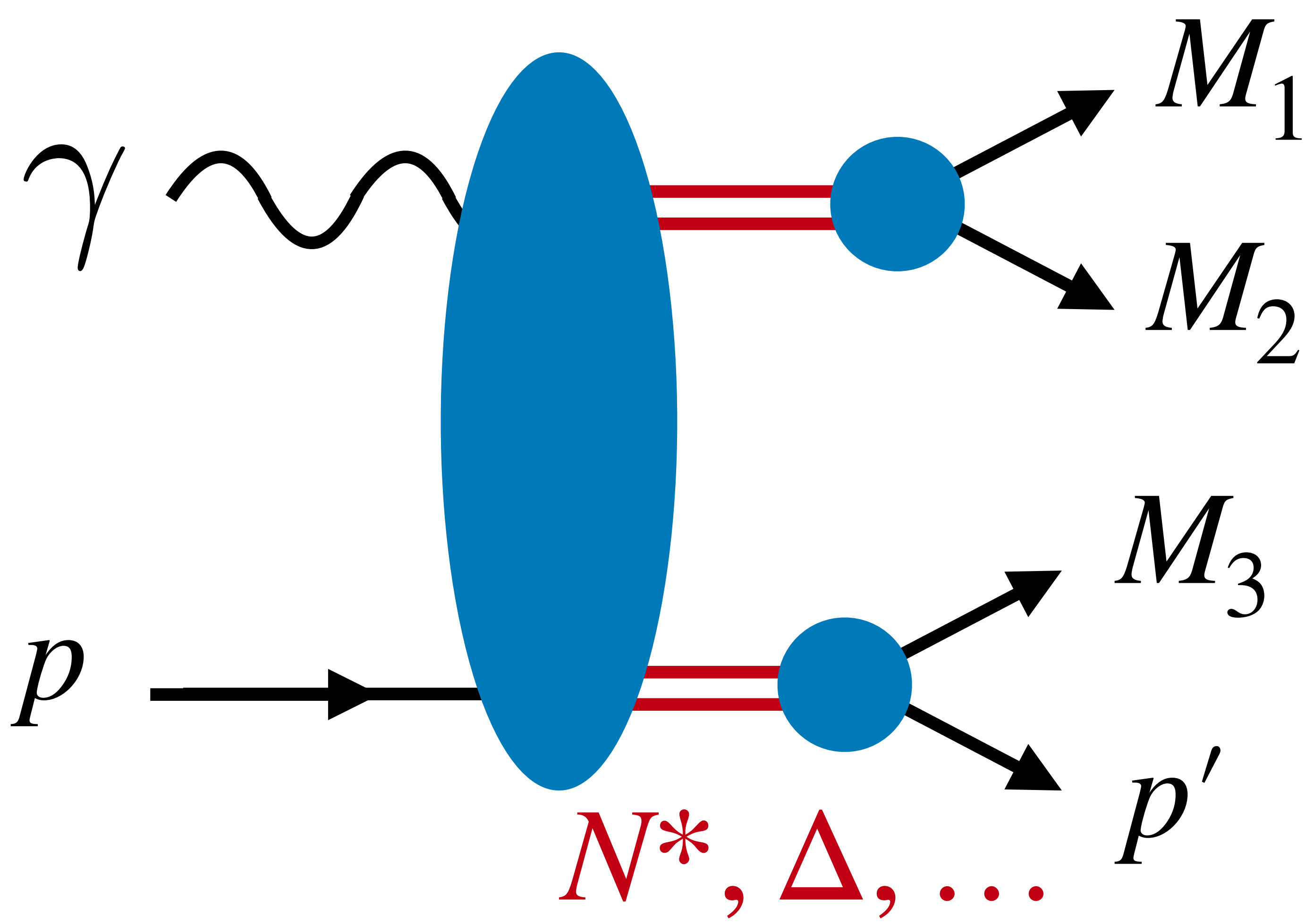


Future directions

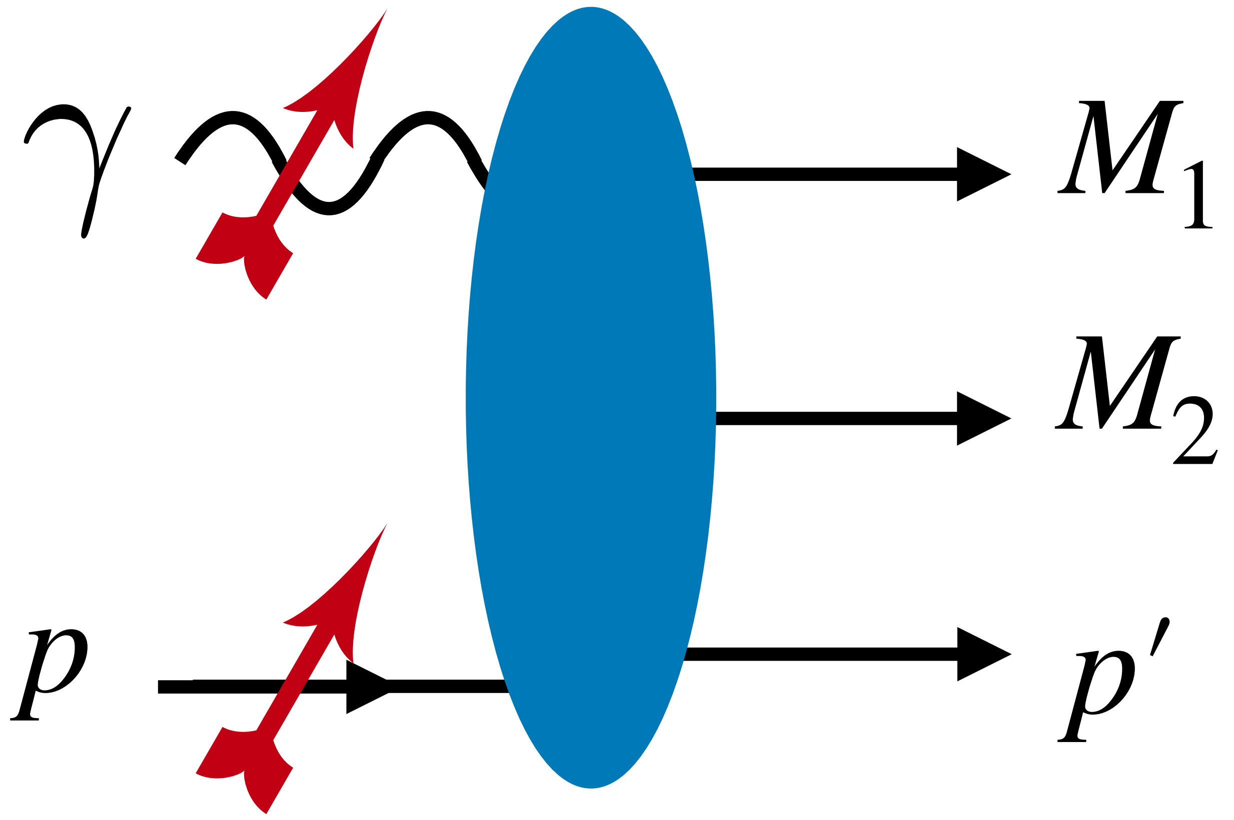
Understand joined SDME / joined Moments

Main decay channel of the π_1 is $b_1\pi$

$$\gamma p \to \pi_1^- \Delta^{++}, \quad \Delta^{++} \to p\pi^+$$
$$\pi_1^- \to b_1^- \pi^0, \quad b_1^- \to \omega\pi^-, \quad \omega \to \pi^+\pi^-\pi^0$$



Which observables with polarized target



How can they help?