Photoproduction of Baryons

Vincent MATHIEU

University of Barcelona

Joint Physics Analysis Center
Exotic Hadron Topical Collaboration

NSTAR Conference
Sevilla
September 2026

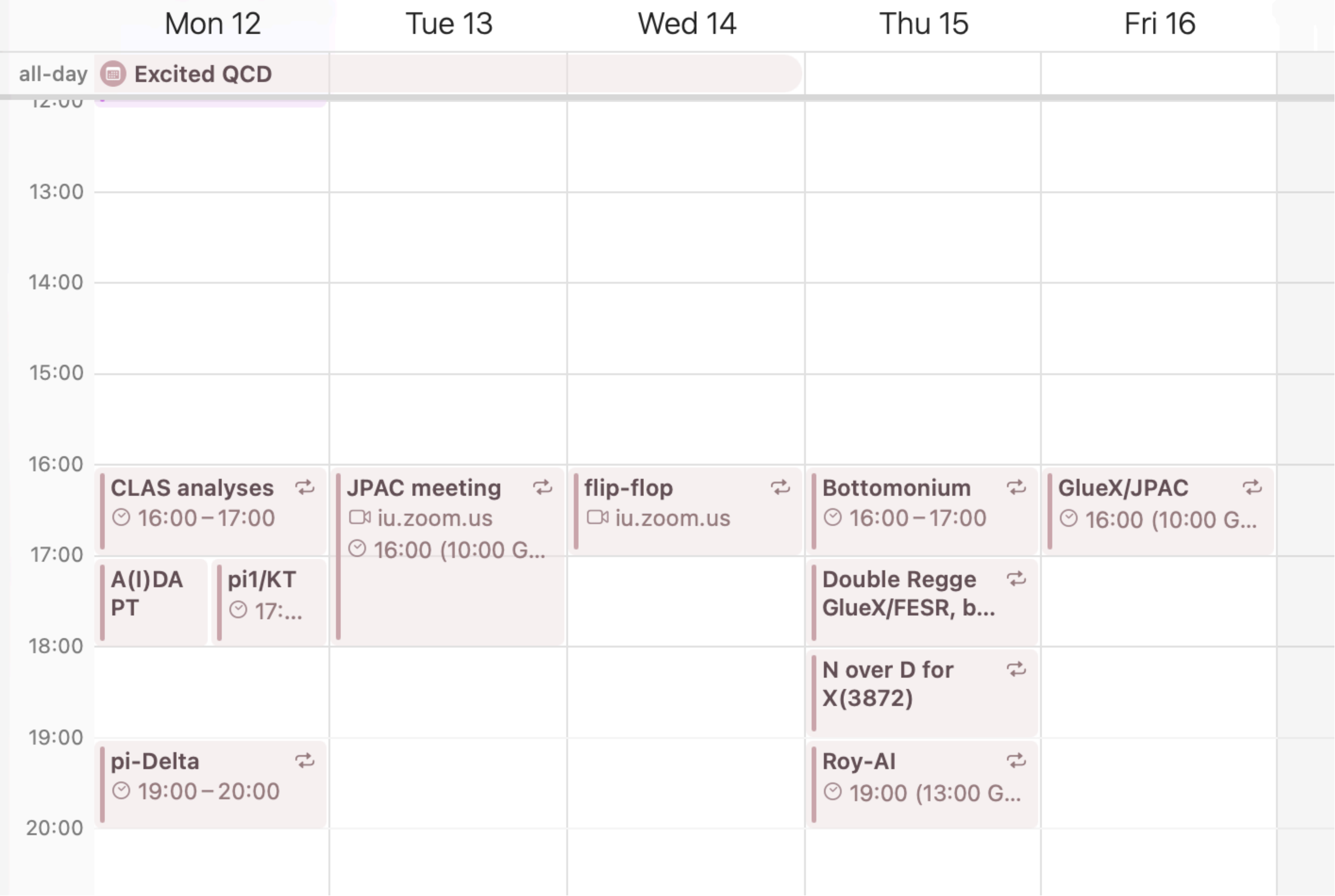
Joint Physics Analysis Center

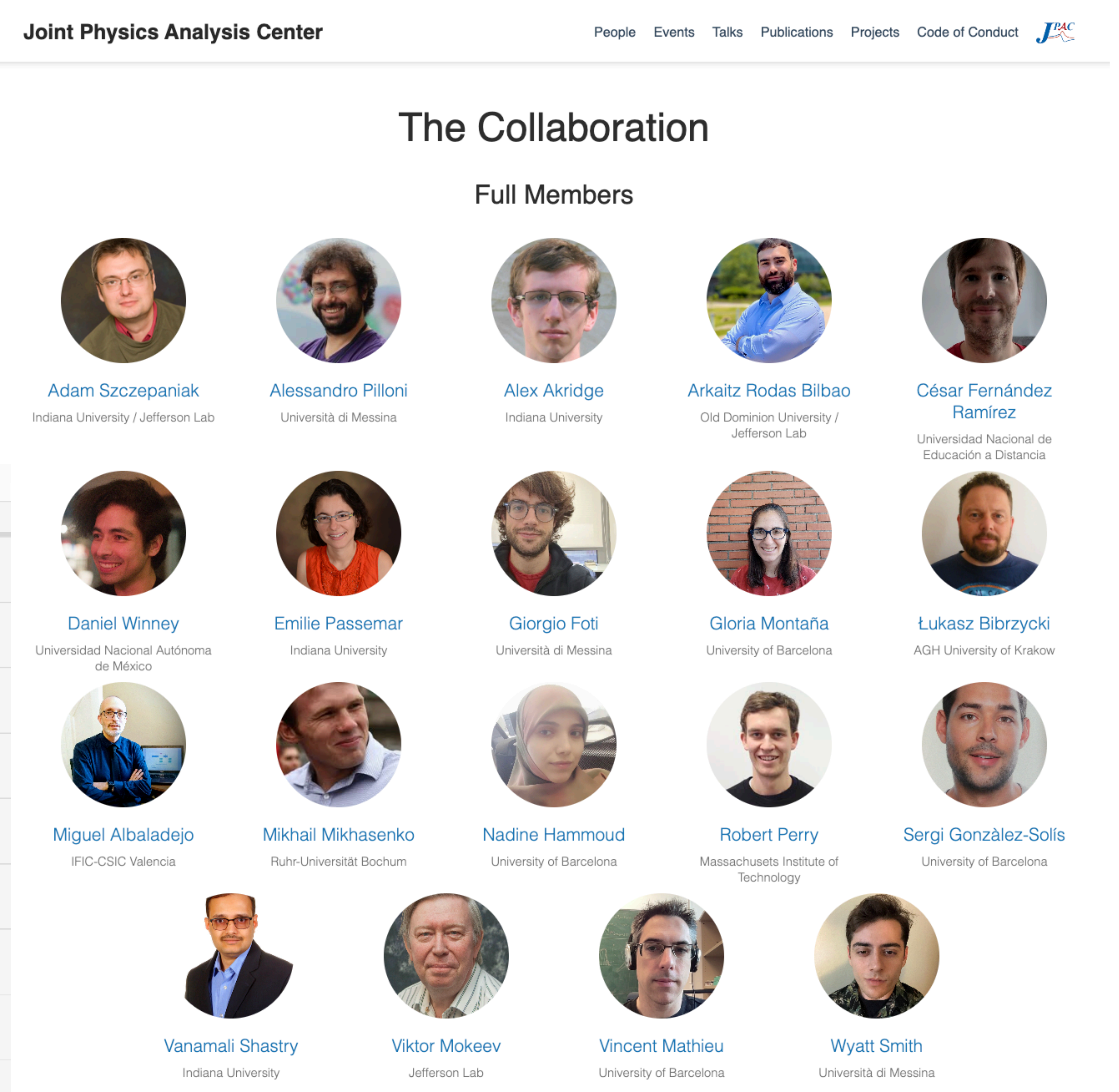
Website:

https://www.jpac-physics.org/

Shared tools:

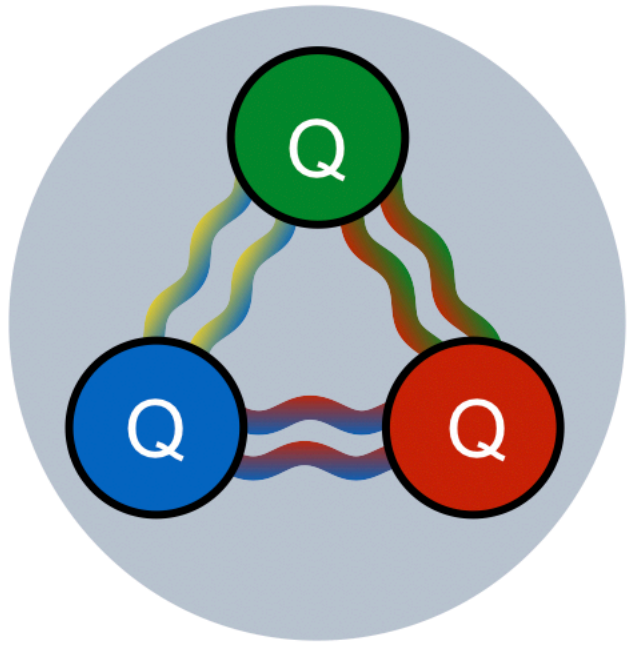
Zoom, Slack, Calendar, Overleaf,…





Ordinary and Exotic Hadrons

Ordinary baryons

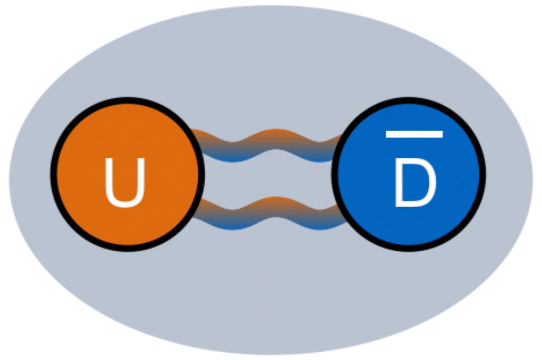


proton stable

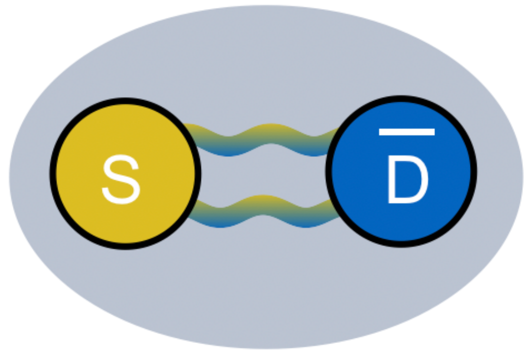
neutron $\tau \sim 10^3 s$

baryon Λ $\tau \sim 10^{-10} s$

Ordinary mesons



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



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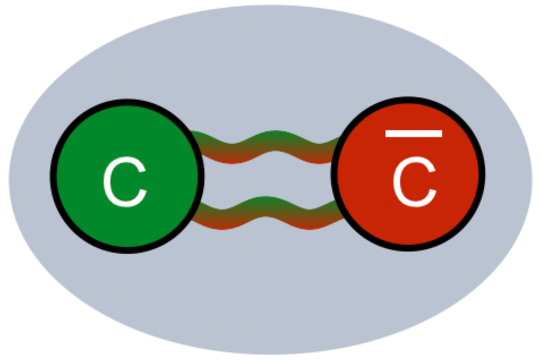

J/ψ $\tau \sim 10^{-20} s$

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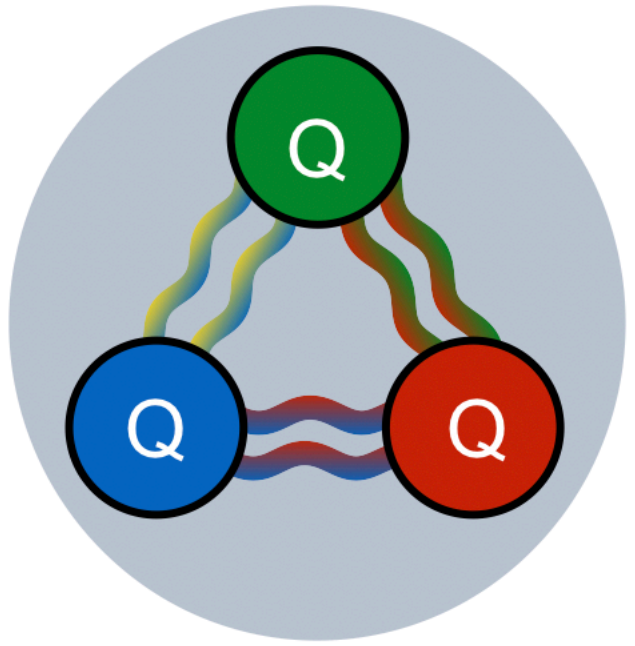

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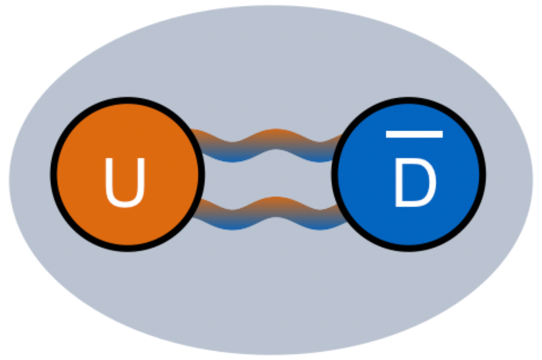

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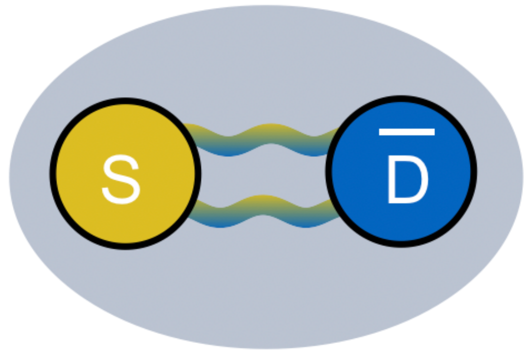

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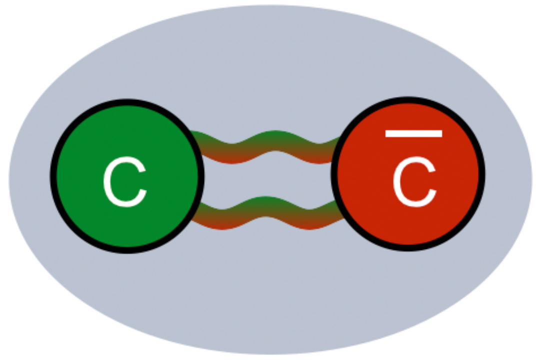

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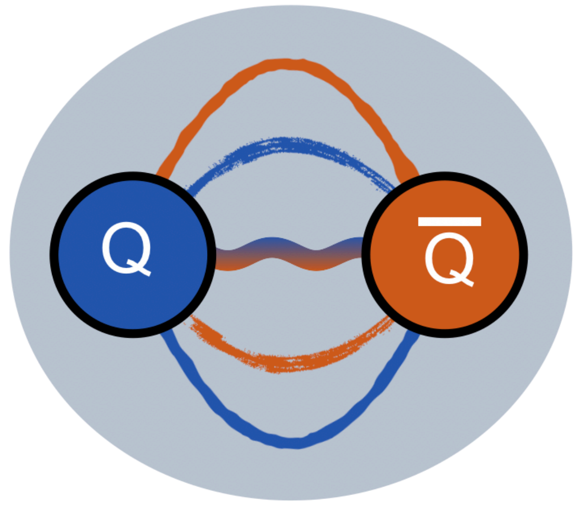
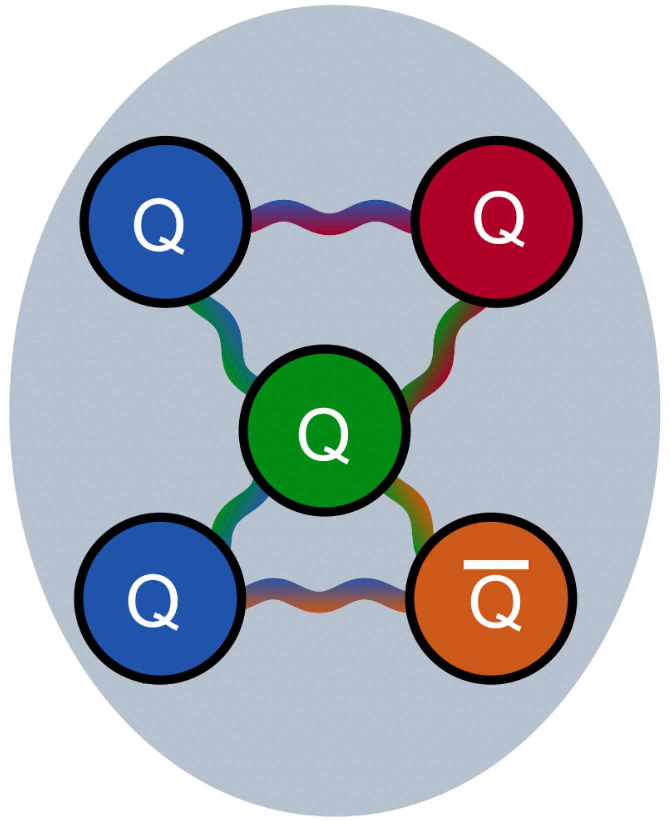
Exotic matter

hybrid mesons

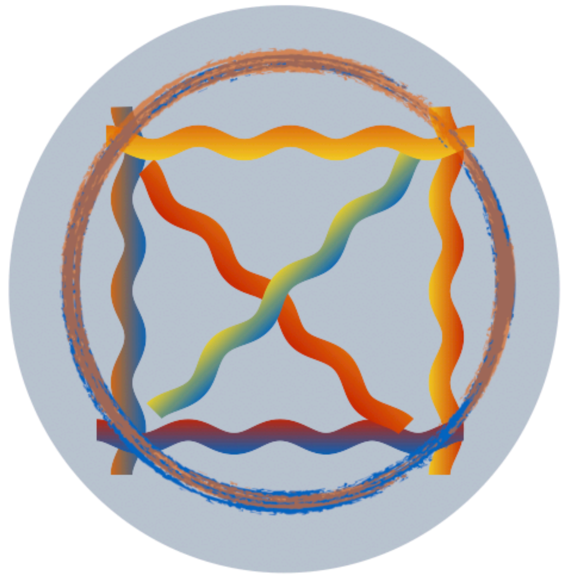


tetraquarks

pentaquarks



glueballs



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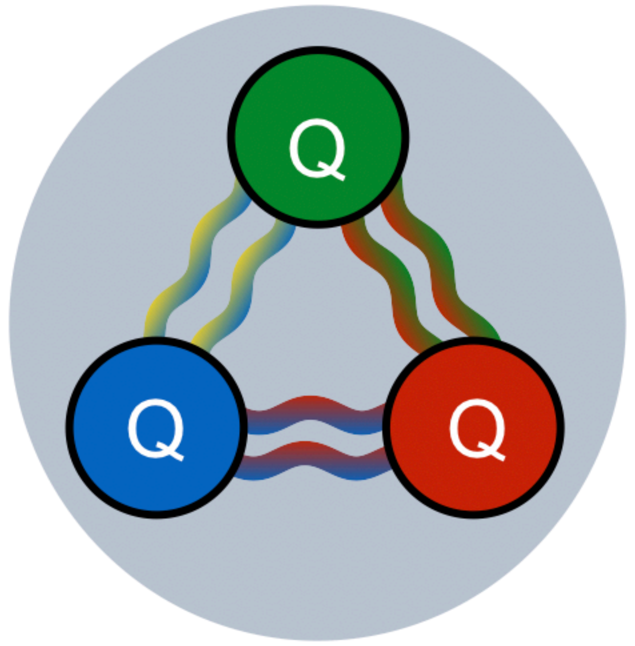

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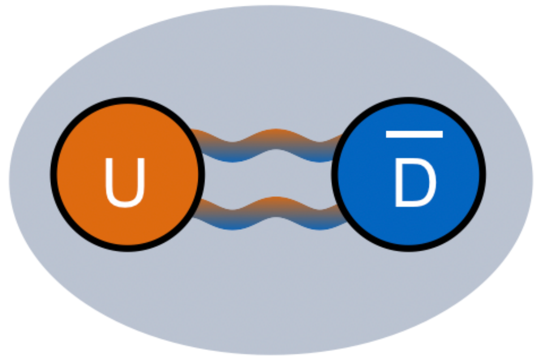

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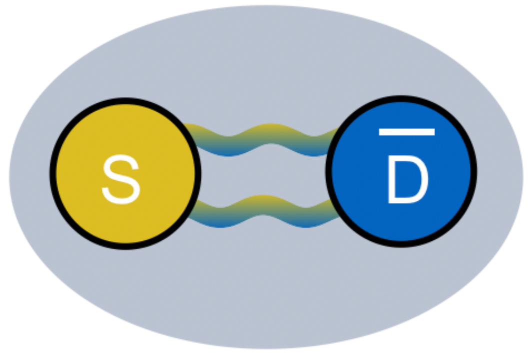

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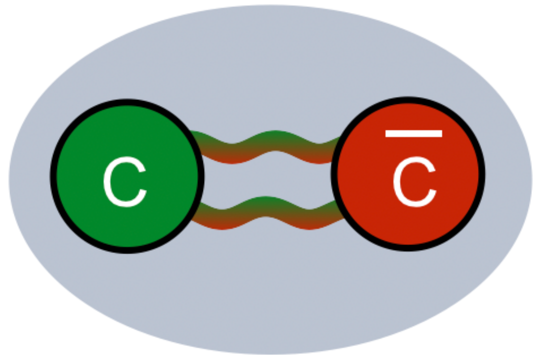

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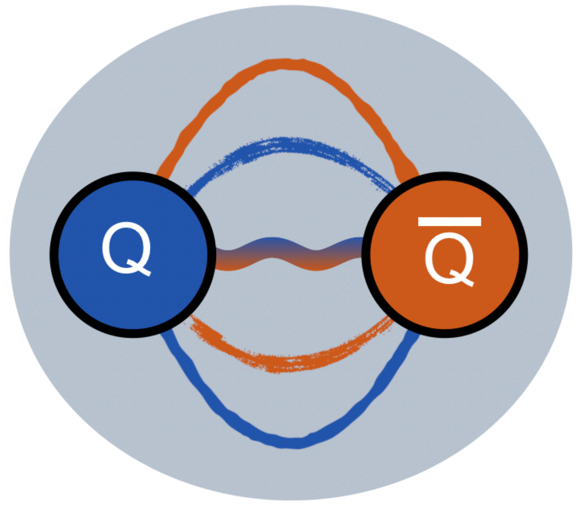

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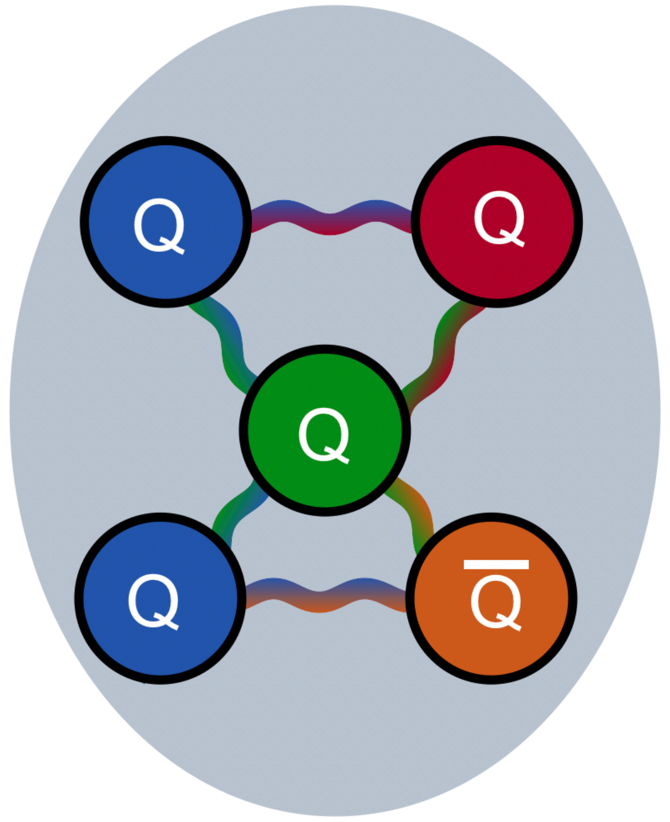

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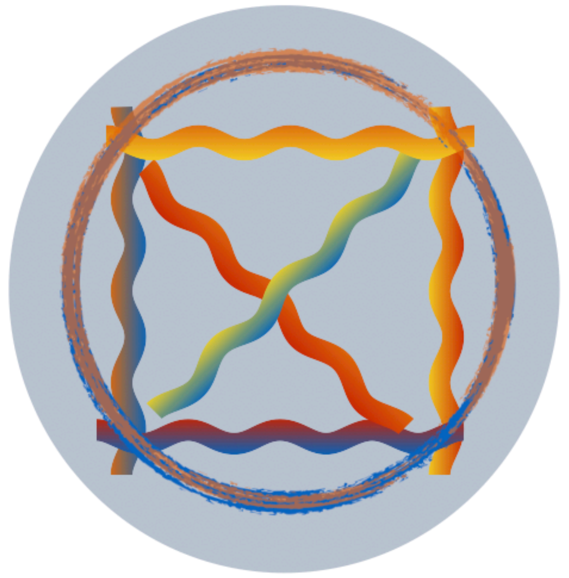

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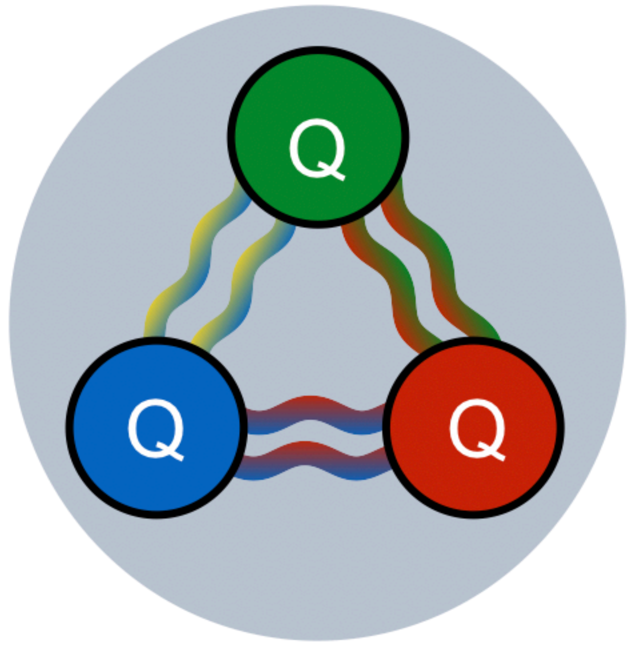

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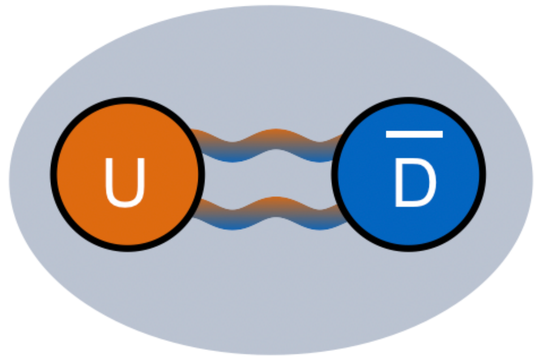

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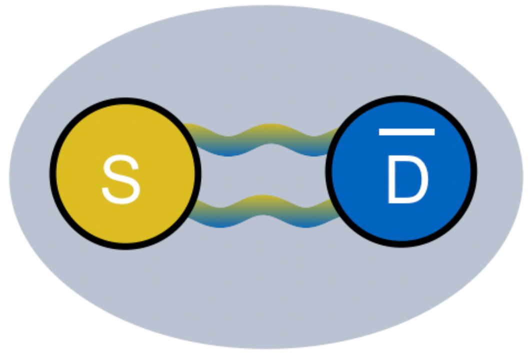

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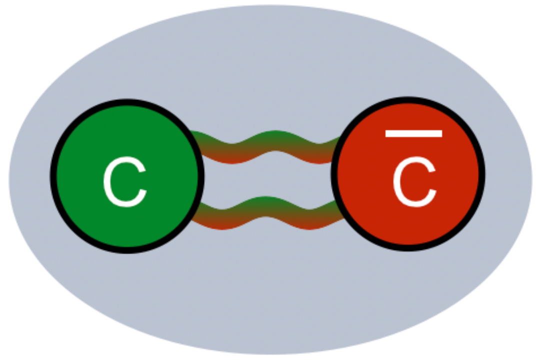

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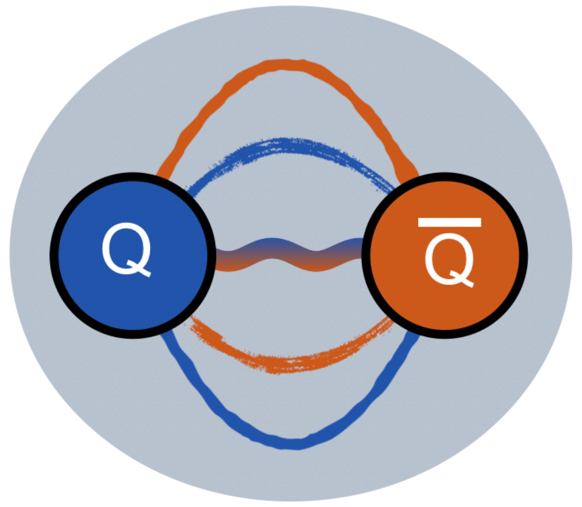


Meson with excited gluon field

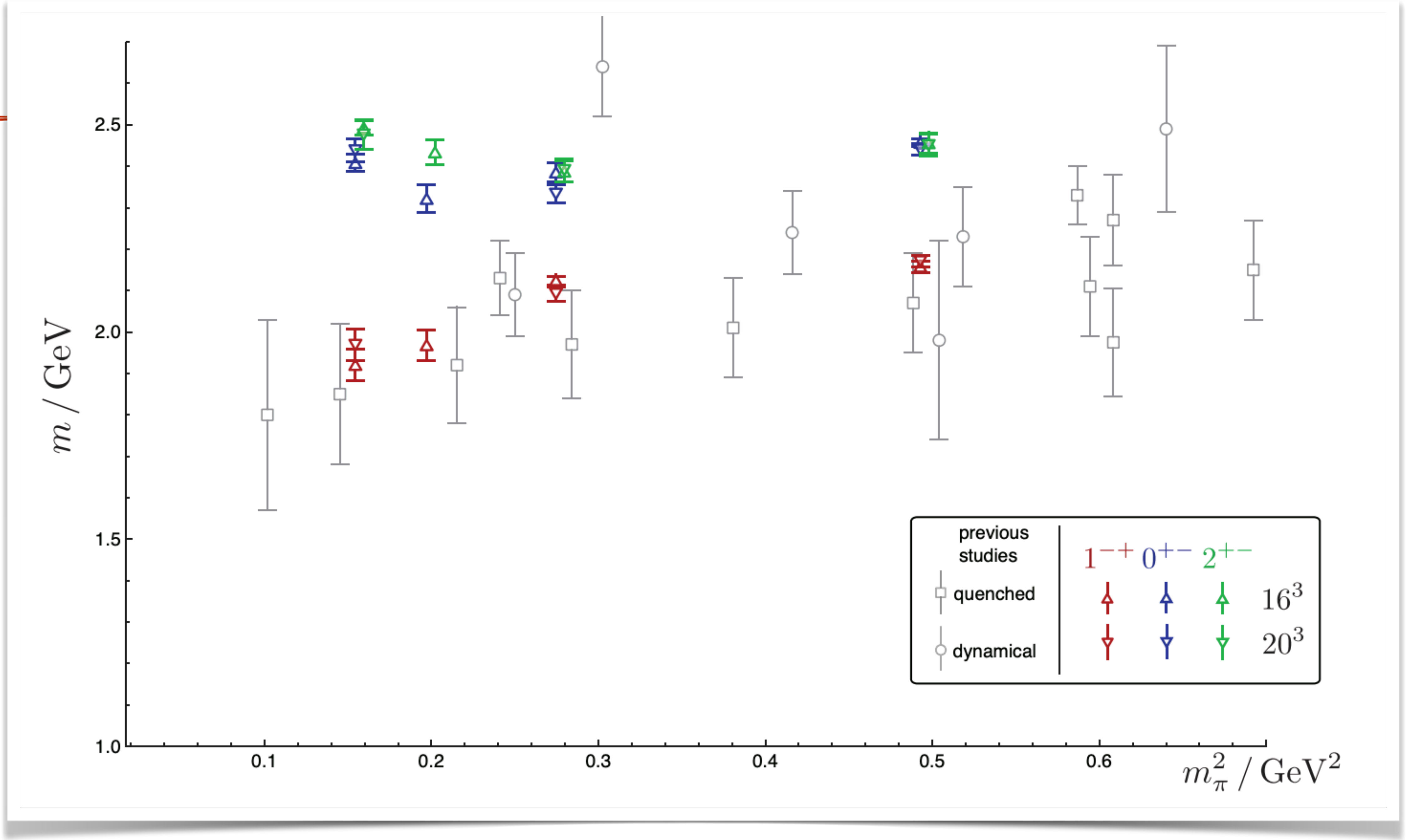
Gluon field may carry quantum numbers

Lattice QCD on the Lightest Exotic

The lightest isovector exotic meson is the

$$\pi_1(1^{-+})$$

$\pi_1(1^{-+})$ couples to $\eta\pi$, $\eta'\pi$, 3π, $b_1\pi$, $\omega\rho$, …



HadSpec PRD82 (2010) 034508

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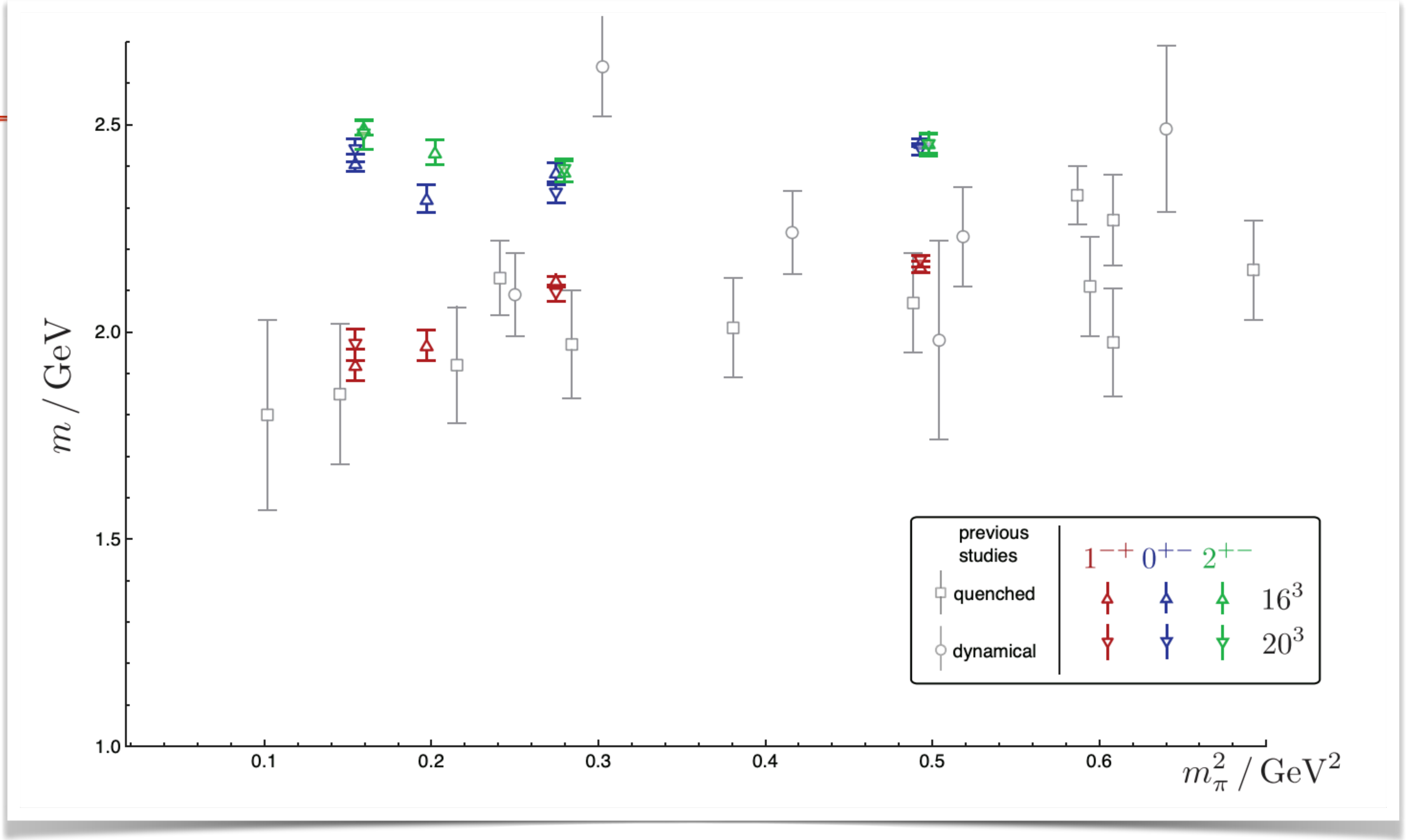
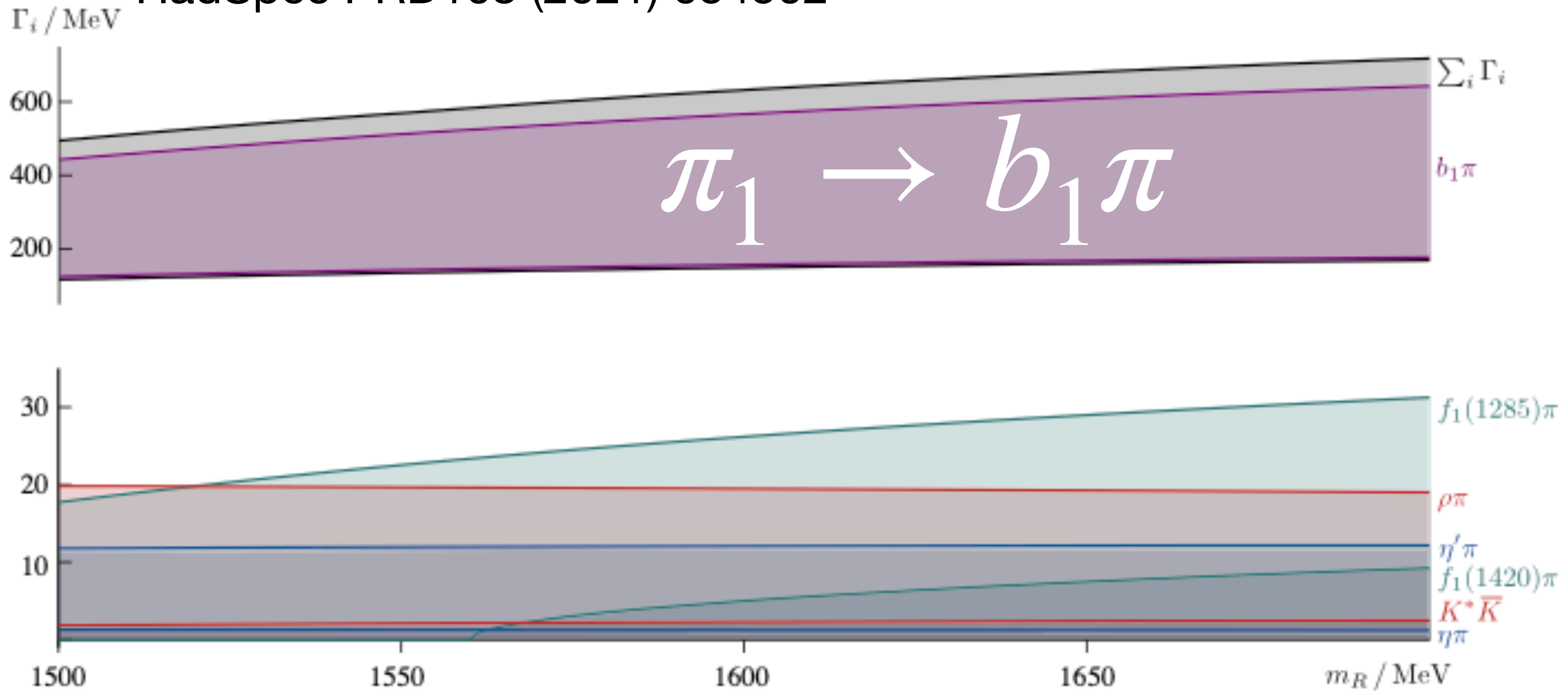


HadSpec PRD82 (2010) 034508

HadSpec PRD103 (2021) 054502



Its main decay channel is $\pi_1 \to b_1\pi$

Easiest decay mode is $\pi_1 \to \eta\pi$

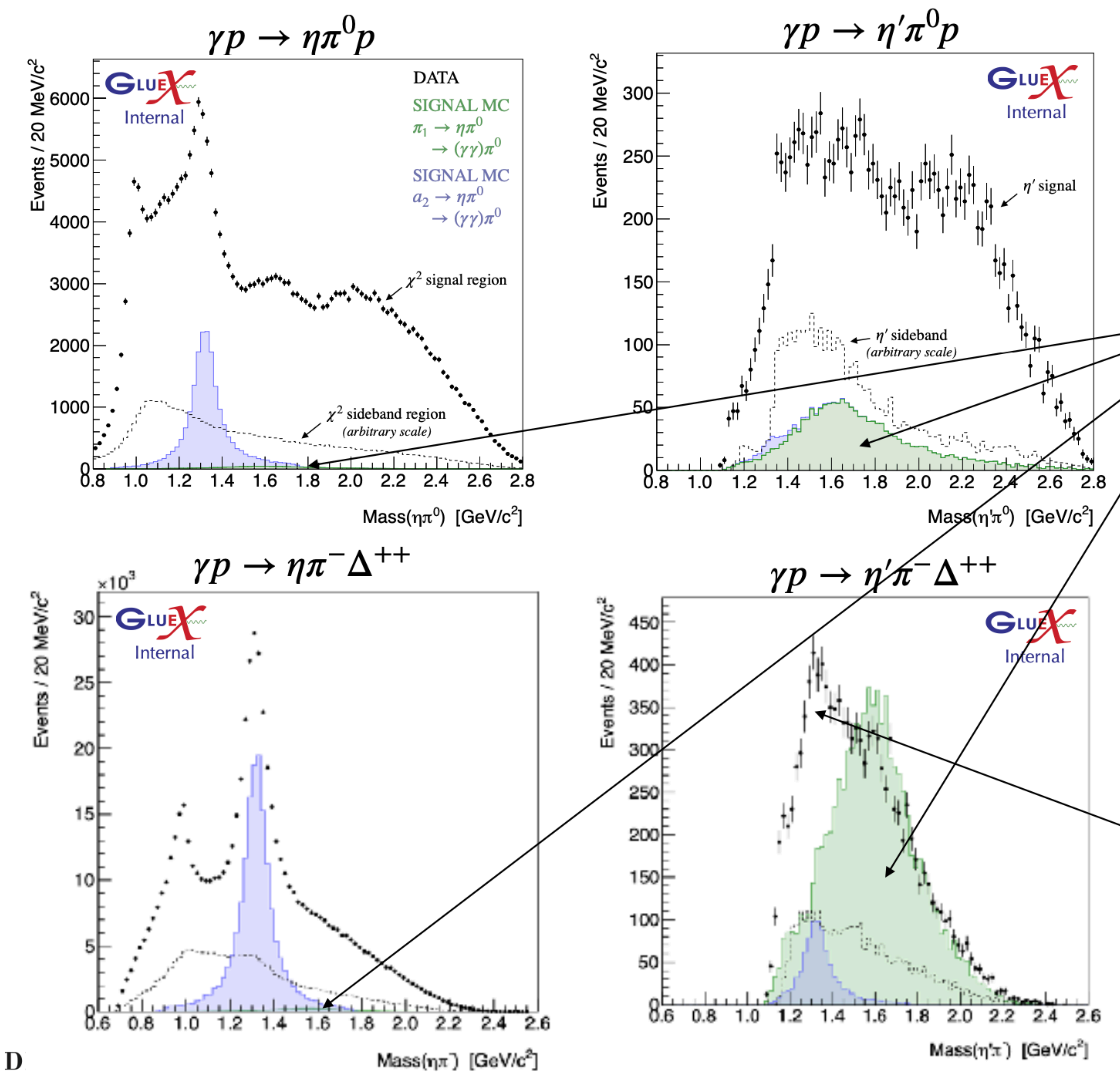
Where (not) to look for the π_1 in GlueX data?

GlueX, PLB133 (2024) 26
arXiv:2407.03316

Blue is the a_2 signal

Green is the π_1 signal

Enhanced π_1^- signal associated with Δ^{++}



Preliminary upper limits on π_1 contribution

Discovery potential is enhanced if exotic yield is large and the exotic signal is a large fraction of the resonant contribution to a particular reaction.

$a_2(1320)$ as a standard candle and interferometer for a π_1 resonance search.

INDIANA UNIVERSITY
College of Arts and Sciences
Bloomington

21

M. R. Shepherd
INT Workshop
March 23, 2023

Promising channel: $b_1^-\pi^0\Delta^{++}$

Understand joined SDME / joined Moments

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

$$p\pi^+$$

$$\gamma p \to \pi_1^-\Delta^{++}$$

$$b_1^-\pi^0$$

$$\pi^+\pi^-\pi^0$$

$$\omega\pi^-$$

Can we "transpose learning"
from only Δ^{++} production?

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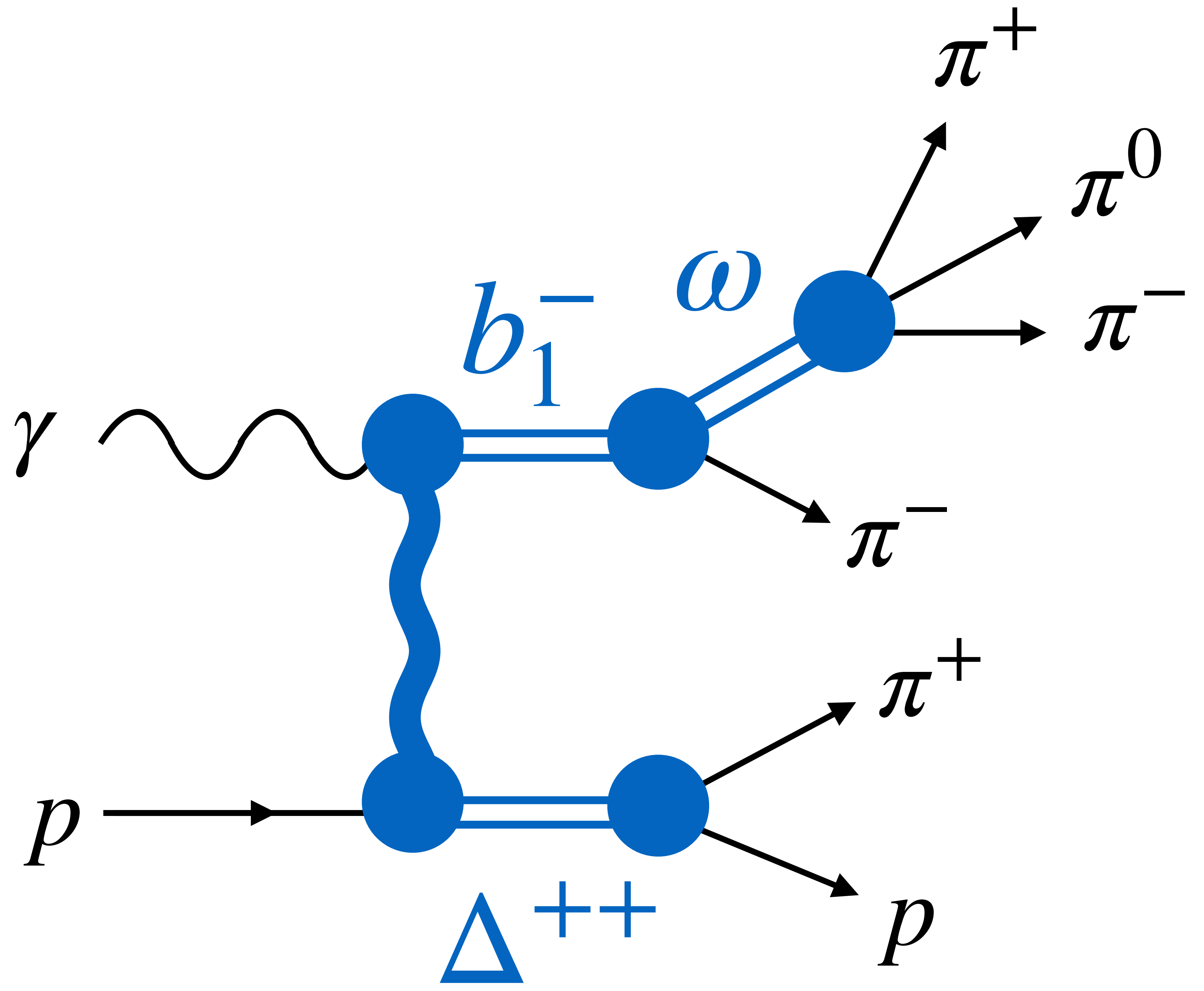
Can GlueX identify properly the b_1 meson?



Ongoing project with the GlueX collaboration

Promising channel: $b_1^- \pi^0 \Delta^{++}$

Understand joined SDME / joined Moments

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

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

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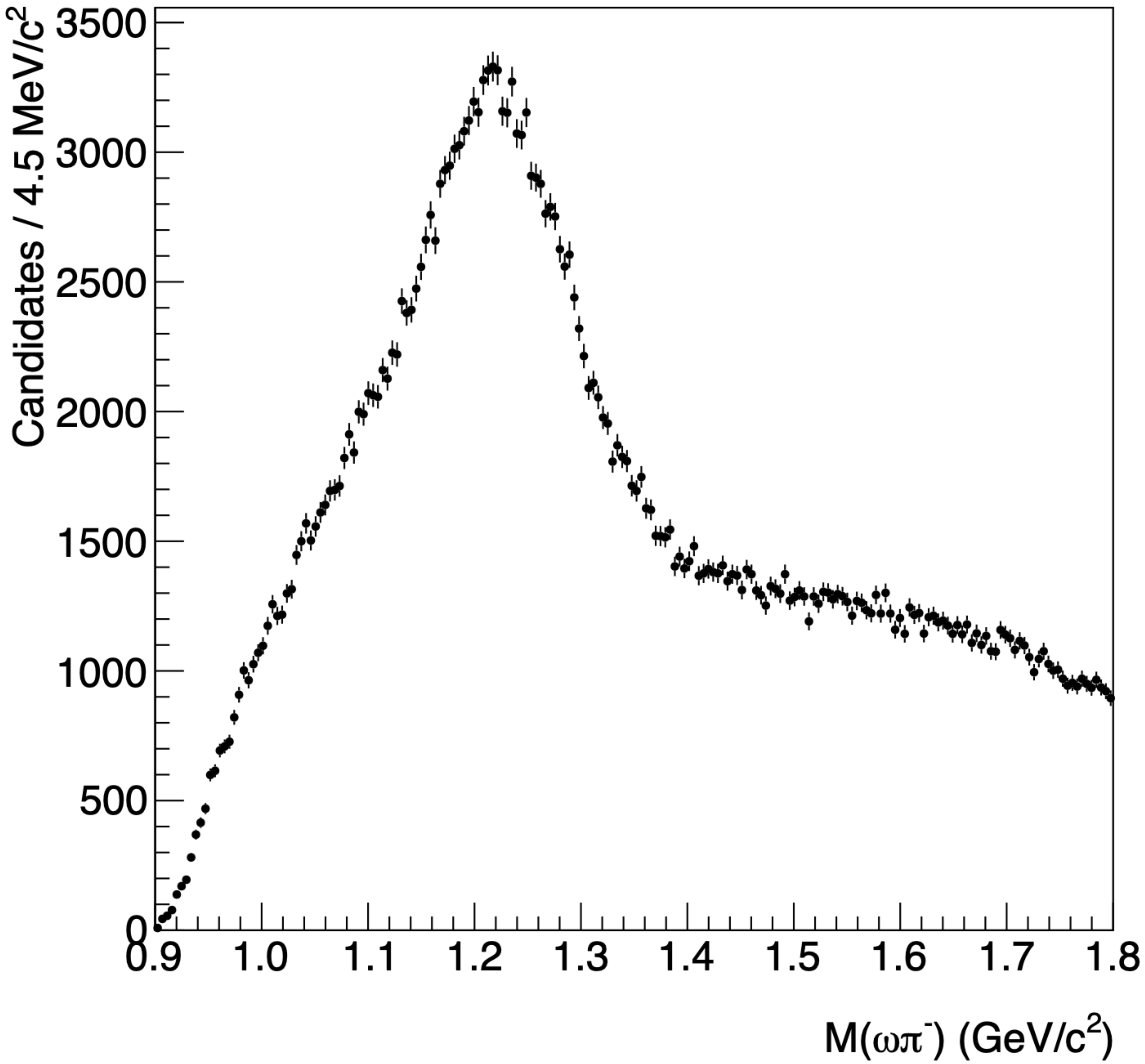

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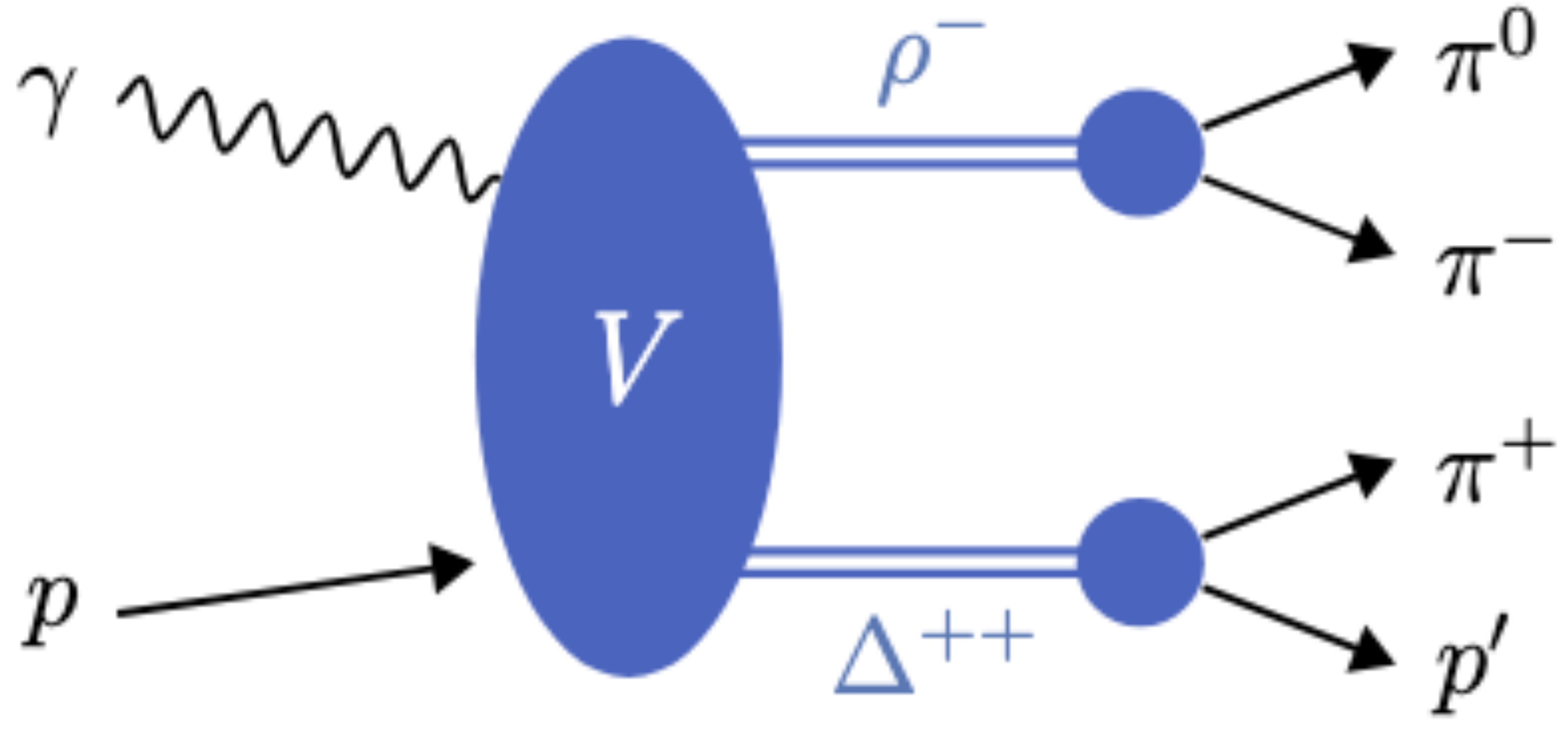
$$\Delta^{++} \to p\pi^+$$

$$\pi_1^- \to b_1^- \pi^0$$

$$b_1^- \to \omega\pi^-$$

$$\omega \to \pi^+\pi^-\pi^0$$

Simplest "meson+baryon" channels



Can we "transpose learning"
from only Δ^{++} production?

Variables and dimensionality

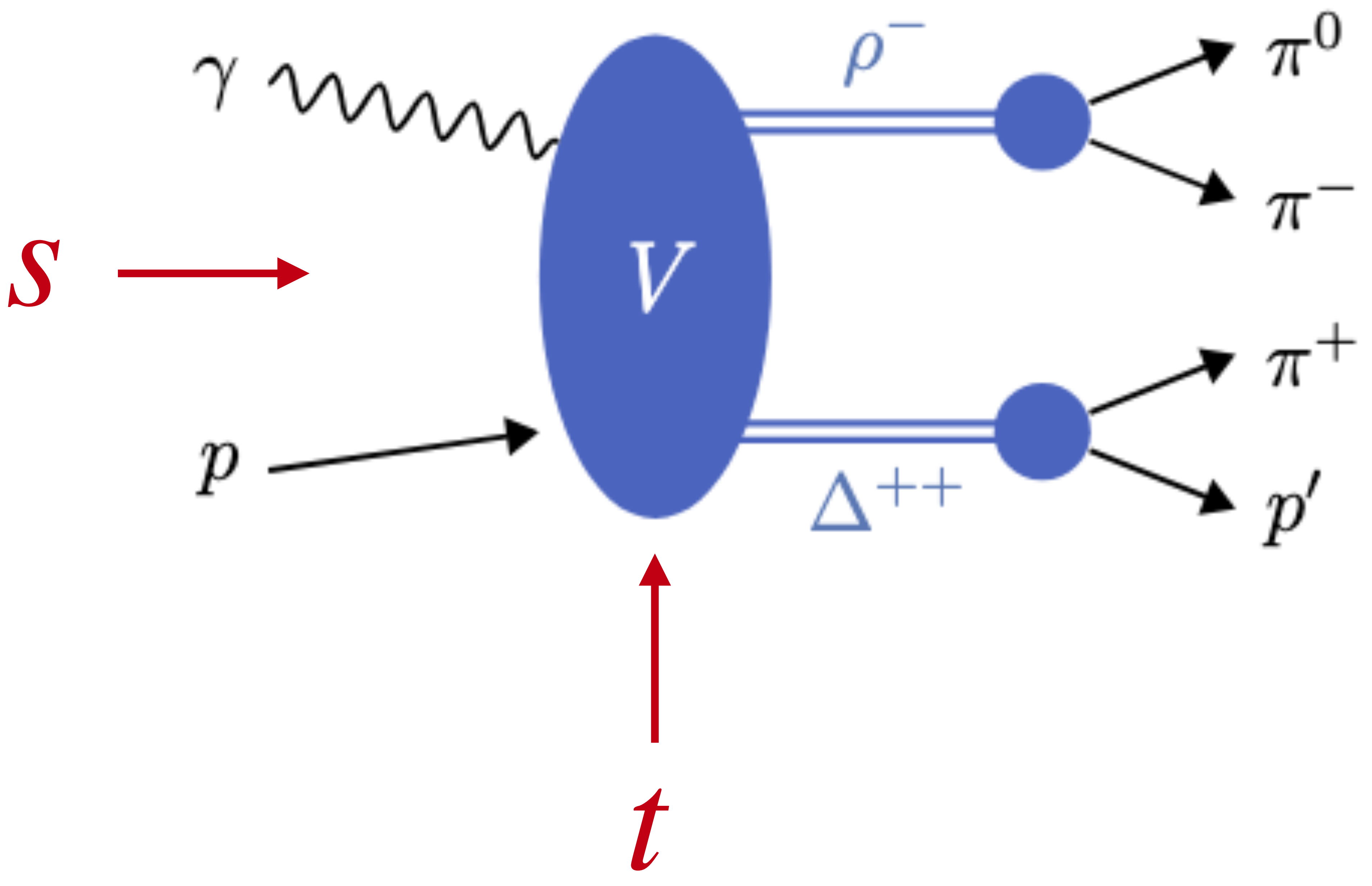
There are $3n-4$ variables for n particles in the final state

The 8 variables for $\rho^-\Delta^{++}$ could be

$$\rho^- \to \pi^-\pi^0: \qquad m^2_{\pi^-\pi^0}, \qquad \Omega_{\pi^-} = (\theta_{\pi^-}, \phi_{\pi^-})$$

$$\Delta^{++} \to \pi^+ p: \qquad m^2_{\pi^+ p}, \qquad \Omega_{\pi^+} = (\theta_{\pi^+}, \phi_{\pi^+})$$

$$\gamma p \to \rho^-\Delta^{++}: \qquad V_{\lambda_\gamma,\lambda_\rho,\lambda_p,\lambda_\Delta}(s,t)$$

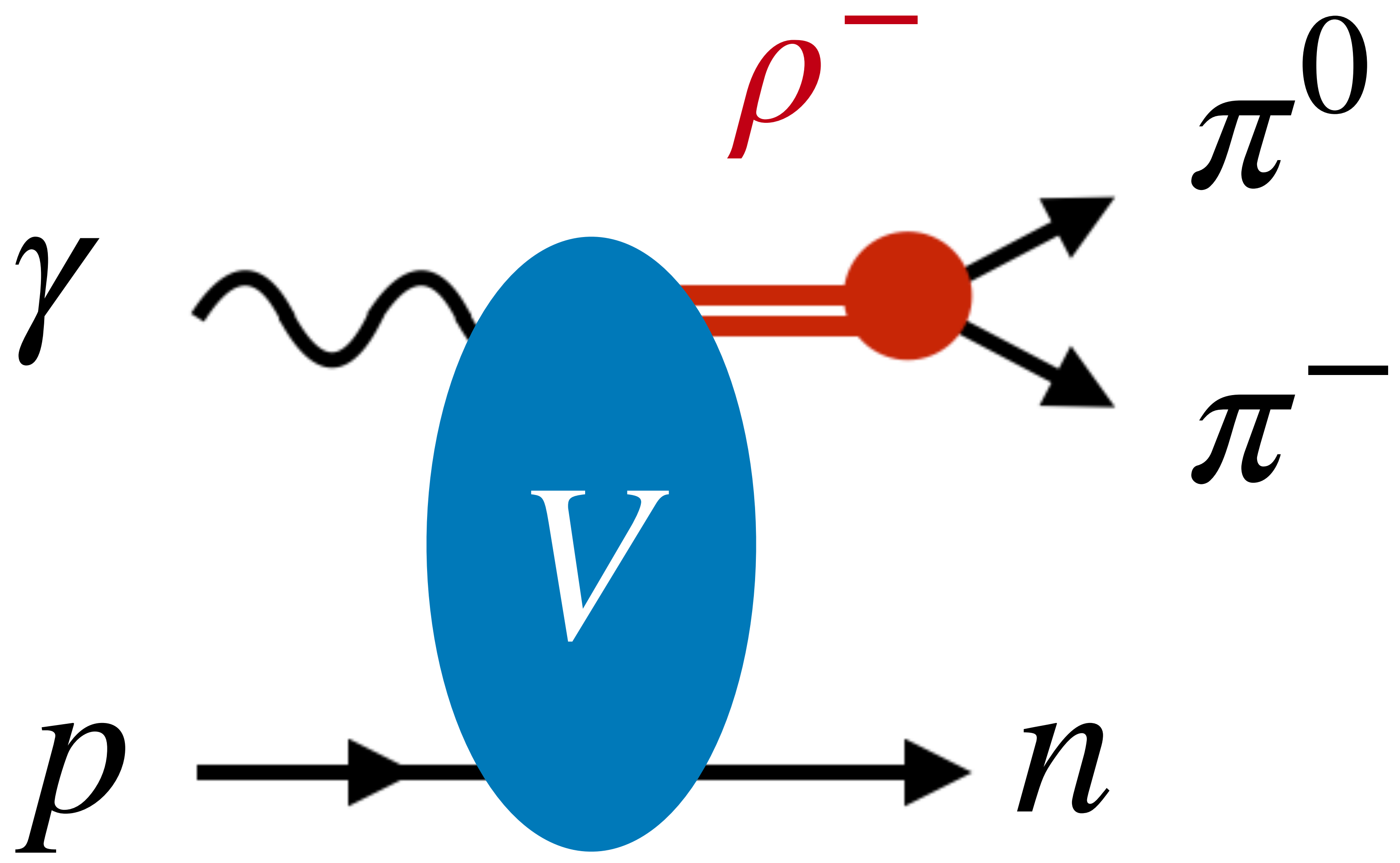


24 complex functions of 2 variables

ρ Spin Density Matrix

Knowing the spin of the resonance:

$$A_{\lambda_\gamma,\lambda_p,\lambda_n}(s,t,\Omega,m^2_{\pi^+\pi^0}) = \sum_m V_{\lambda_\gamma,m,\lambda_p,\lambda_n}(s,t)\ F(m^2_{\pi^-\pi^0})\ Y^1_m(\Omega)$$



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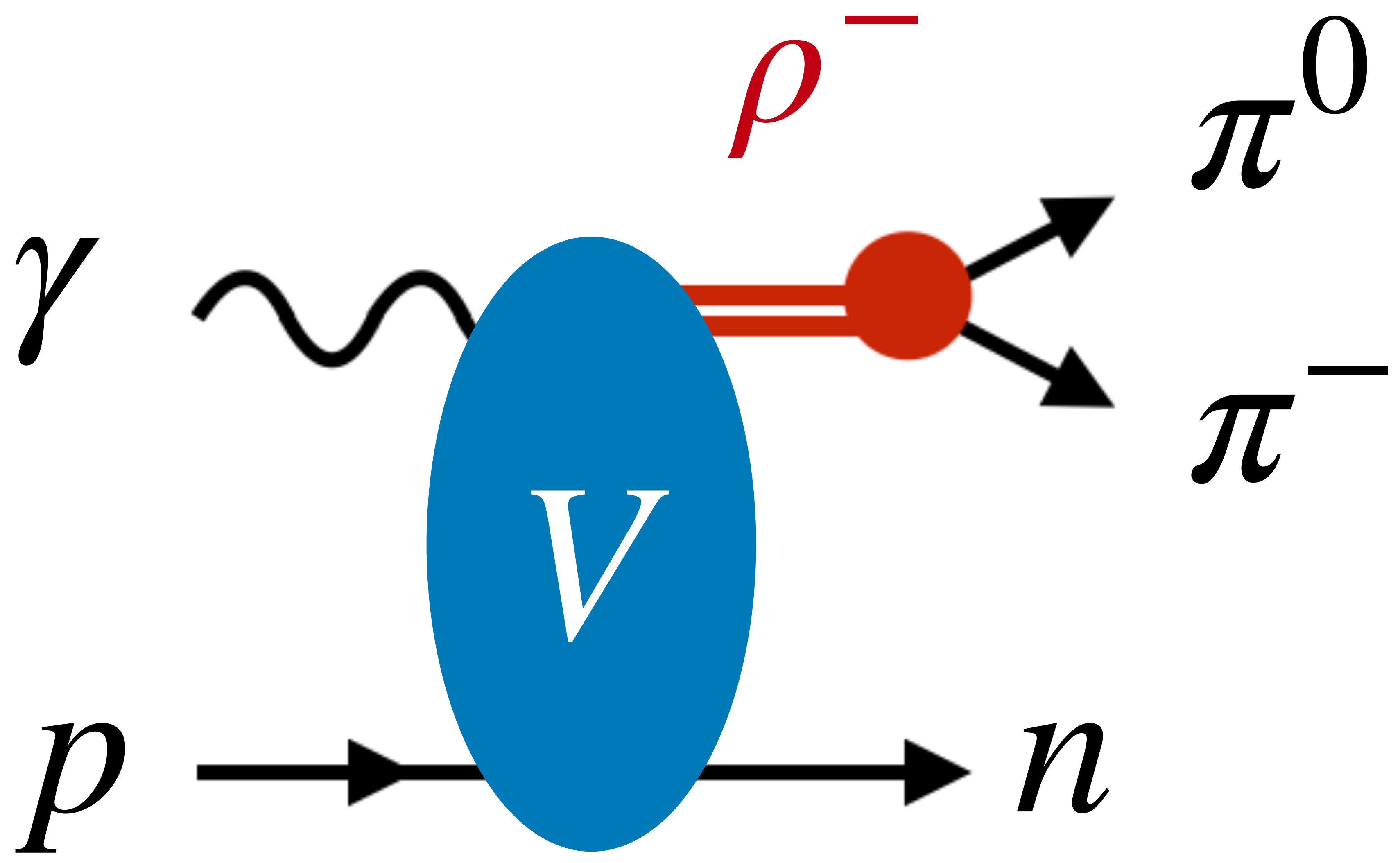

The intensity is the squared:

$$I(\Omega) \propto \sum_{m,m'} Y^1_m(\Omega)\rho_{mm'}(s,t)Y^{1*}_{m'}(\Omega)$$

$$\rho_{mm'}(s,t) = \sum_{\{\lambda\}} V_{\lambda_\gamma,m,\lambda_p,\lambda_n} V^*_{\lambda_\gamma,m',\lambda_p,\lambda_n}$$

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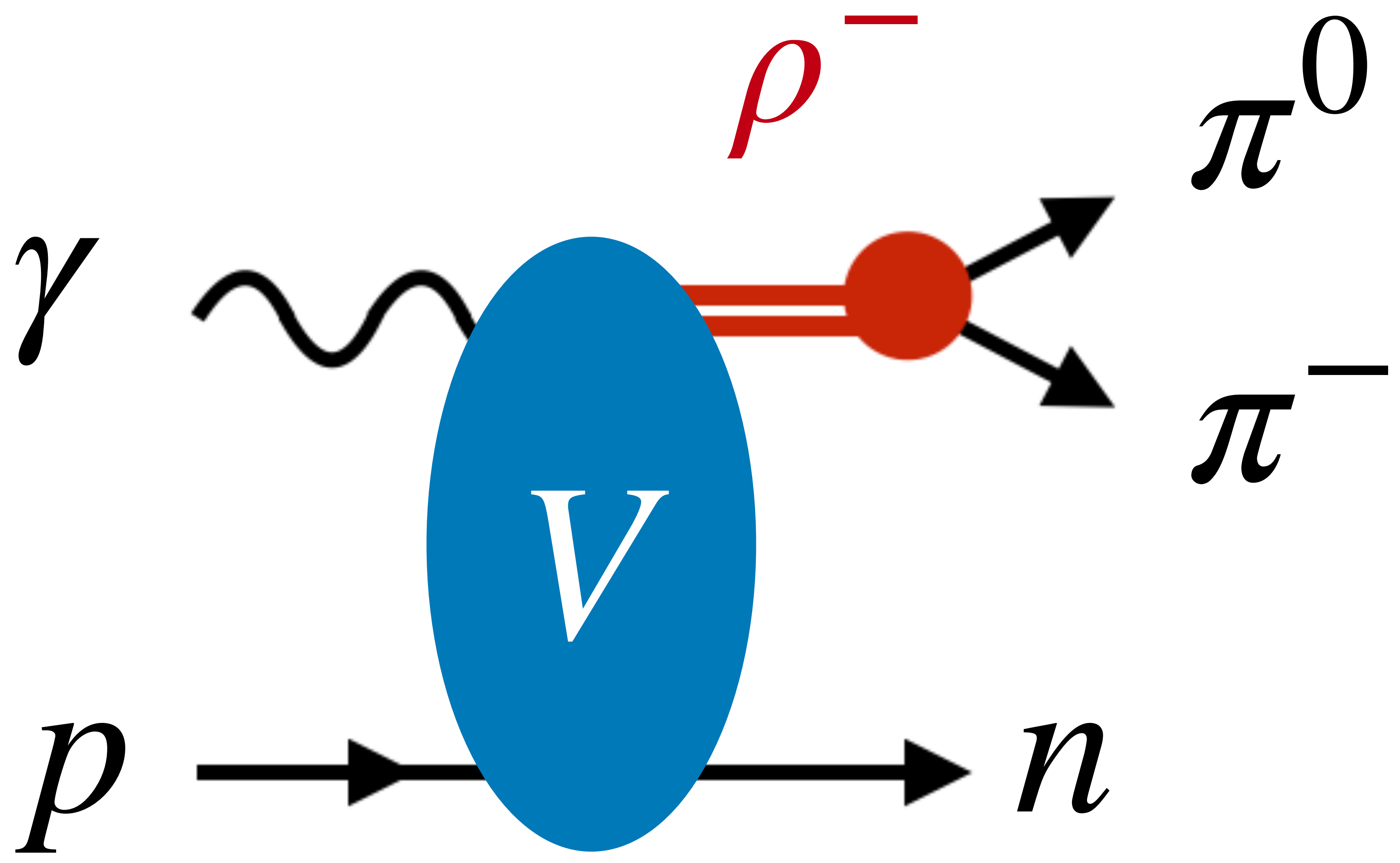

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$$\propto \rho_{00}\cos^2\theta + \rho_{11}\sin^2\theta - \sqrt{2}\rho_{10}\cos\phi\sin 2\theta - \rho_{1-1}\cos 2\phi\sin^2\theta$$

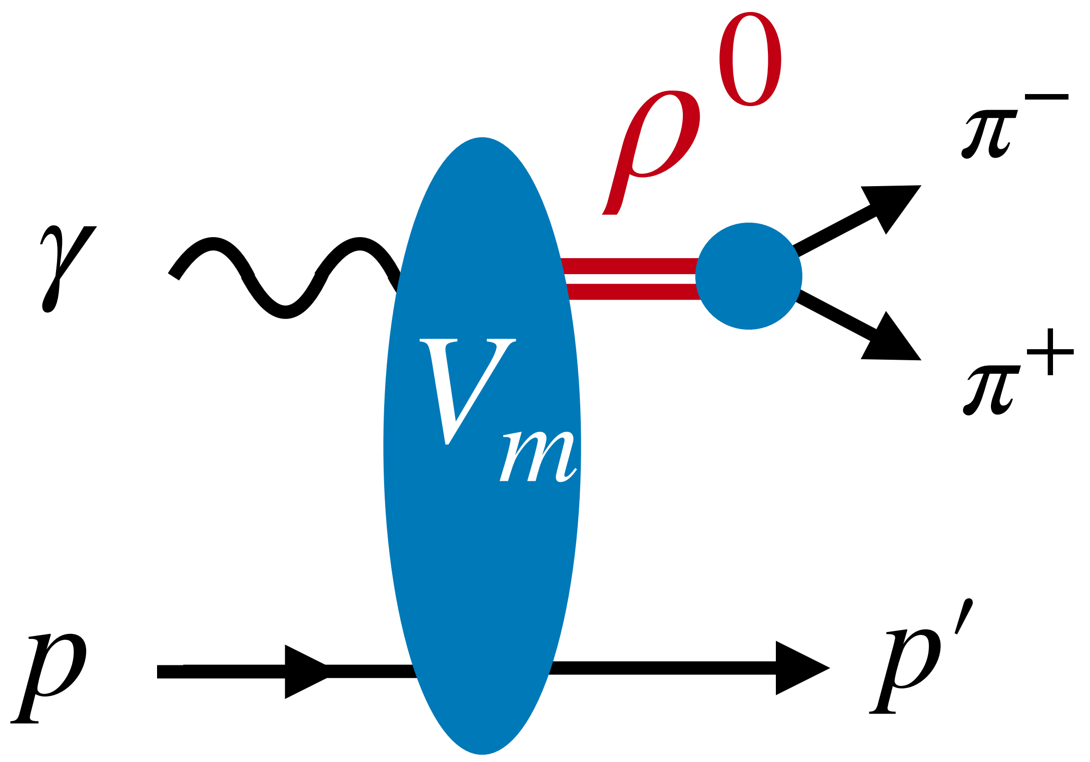
4 SDME extracted from decay angular distribution and provide info on production*

*(4 SDME or 1 diff. cross section + 3 normalized SDME)

$\rho(770)$ Photoproduction @GlueX

Data: GlueX, PRC108 (2023)

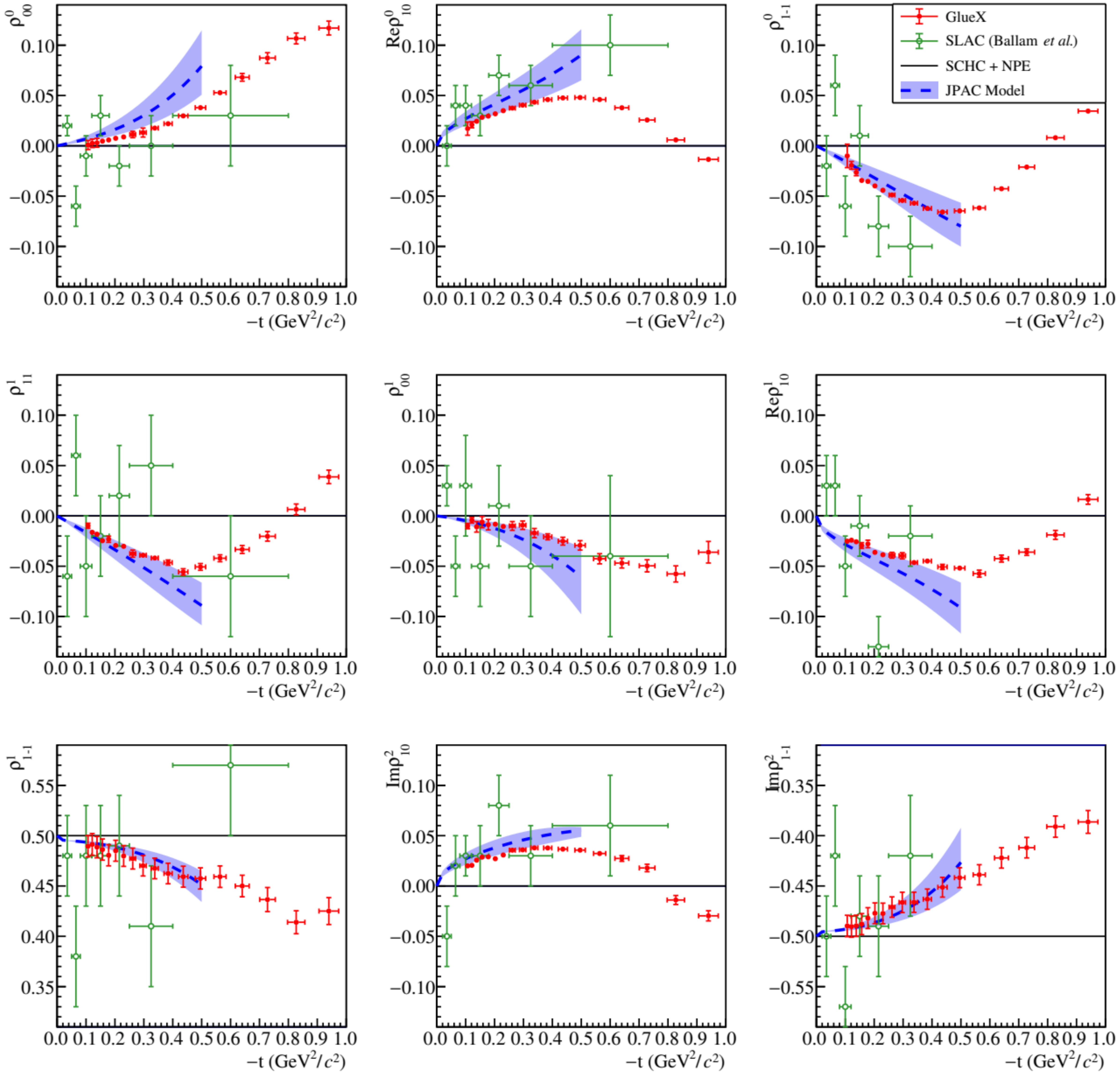
Model: JPAC, PRD97 (2018)



$$\rho^0_{mm'} \sim V_m V^*_{m'}$$

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

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



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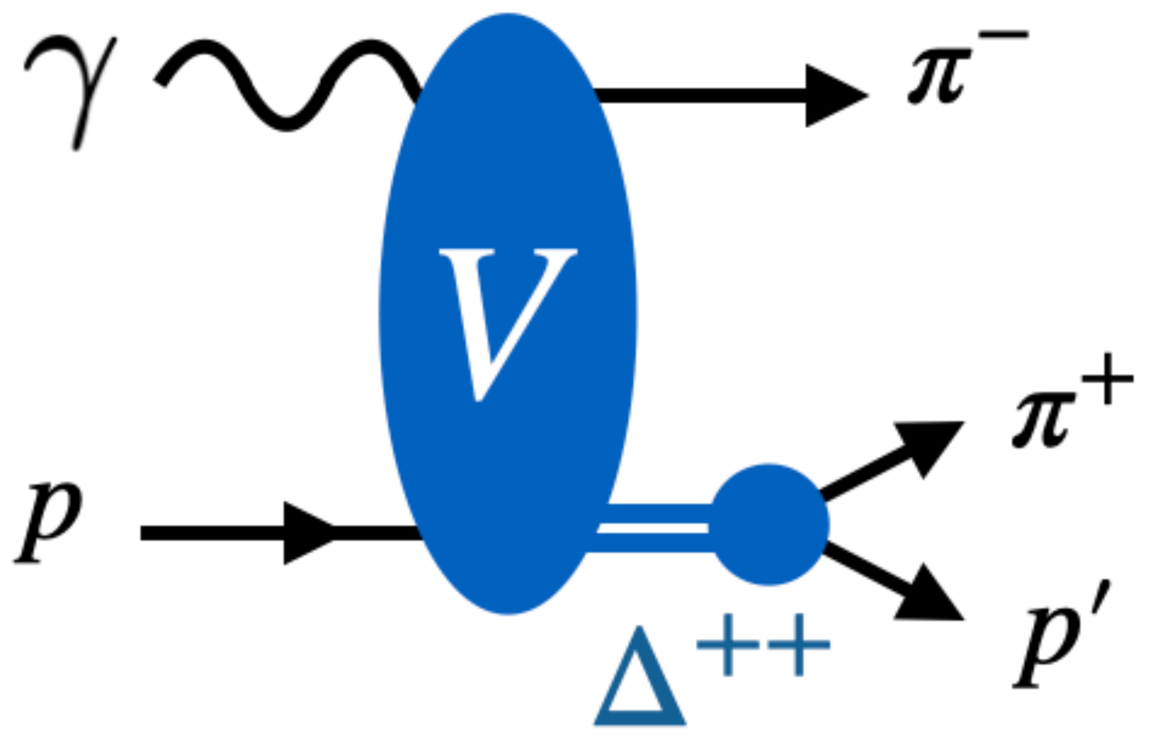

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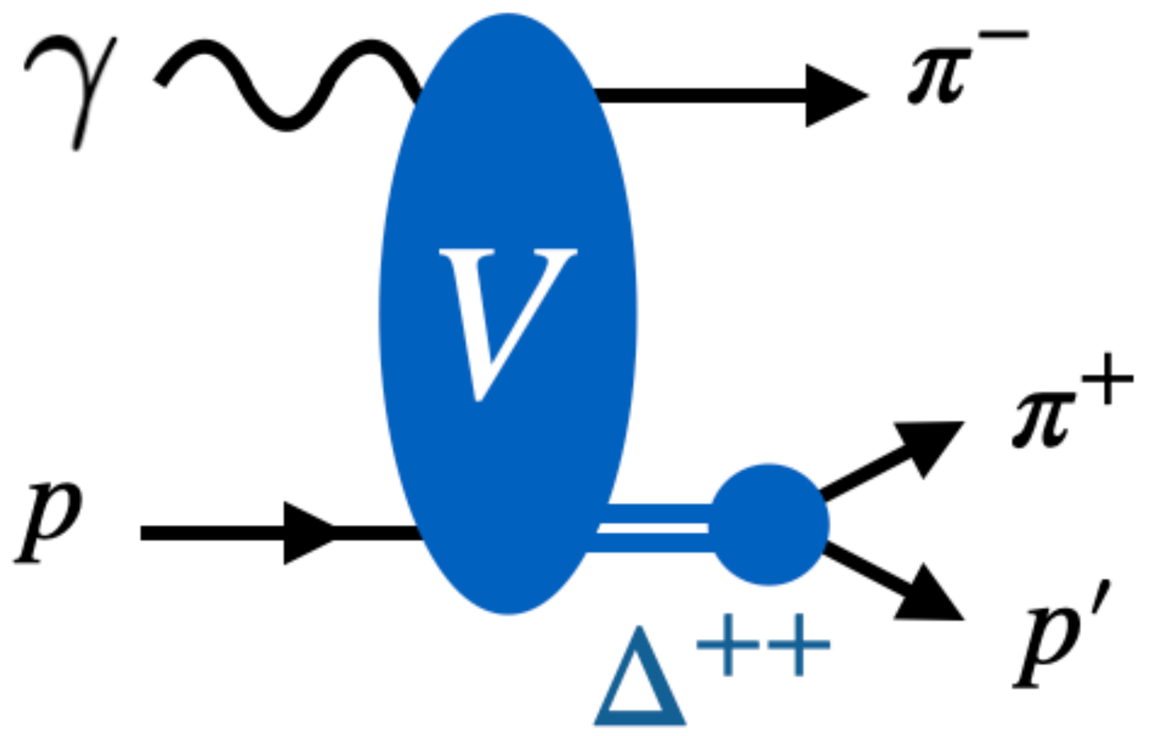

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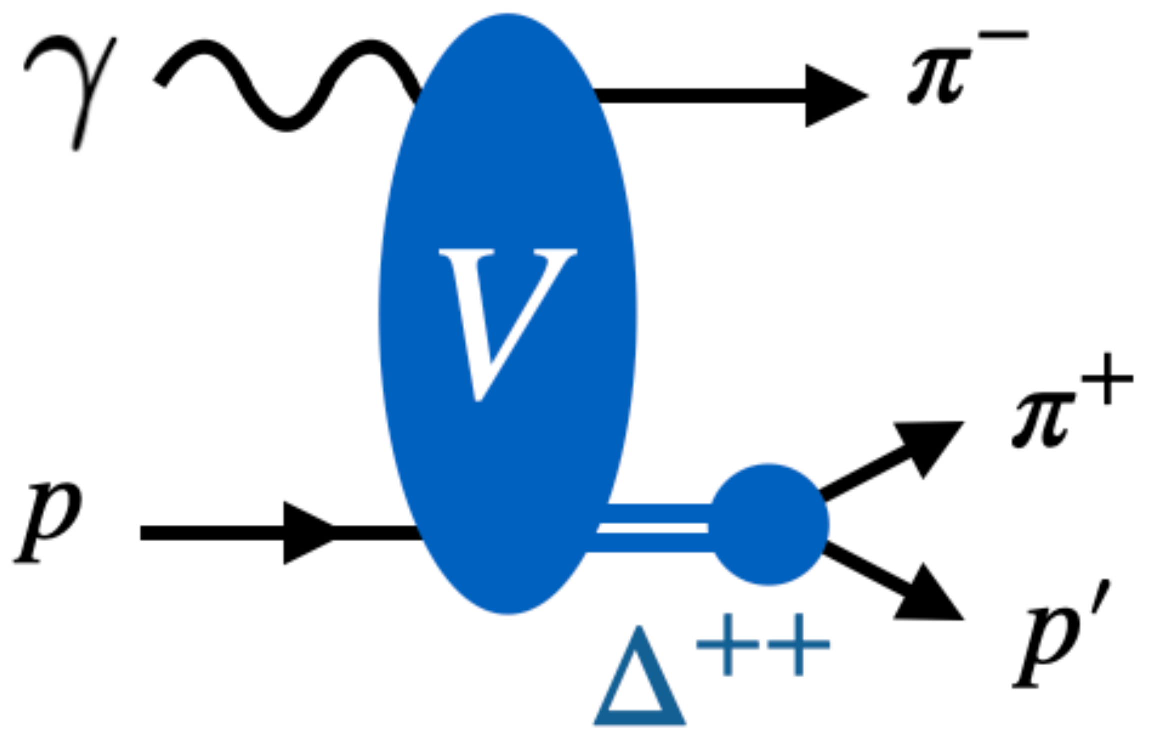

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$$\propto \rho_{11}\left(\frac{1}{3}+\cos^2\theta\right)+\rho_{33}\sin^2\theta-\frac{2}{\sqrt{3}}\left[\rho_{31}\cos\phi\sin 2\theta-\rho_{3-1}\cos 2\phi\sin^2\theta\right]$$

4 SDME extracted from decay angular distribution and provide info on production*

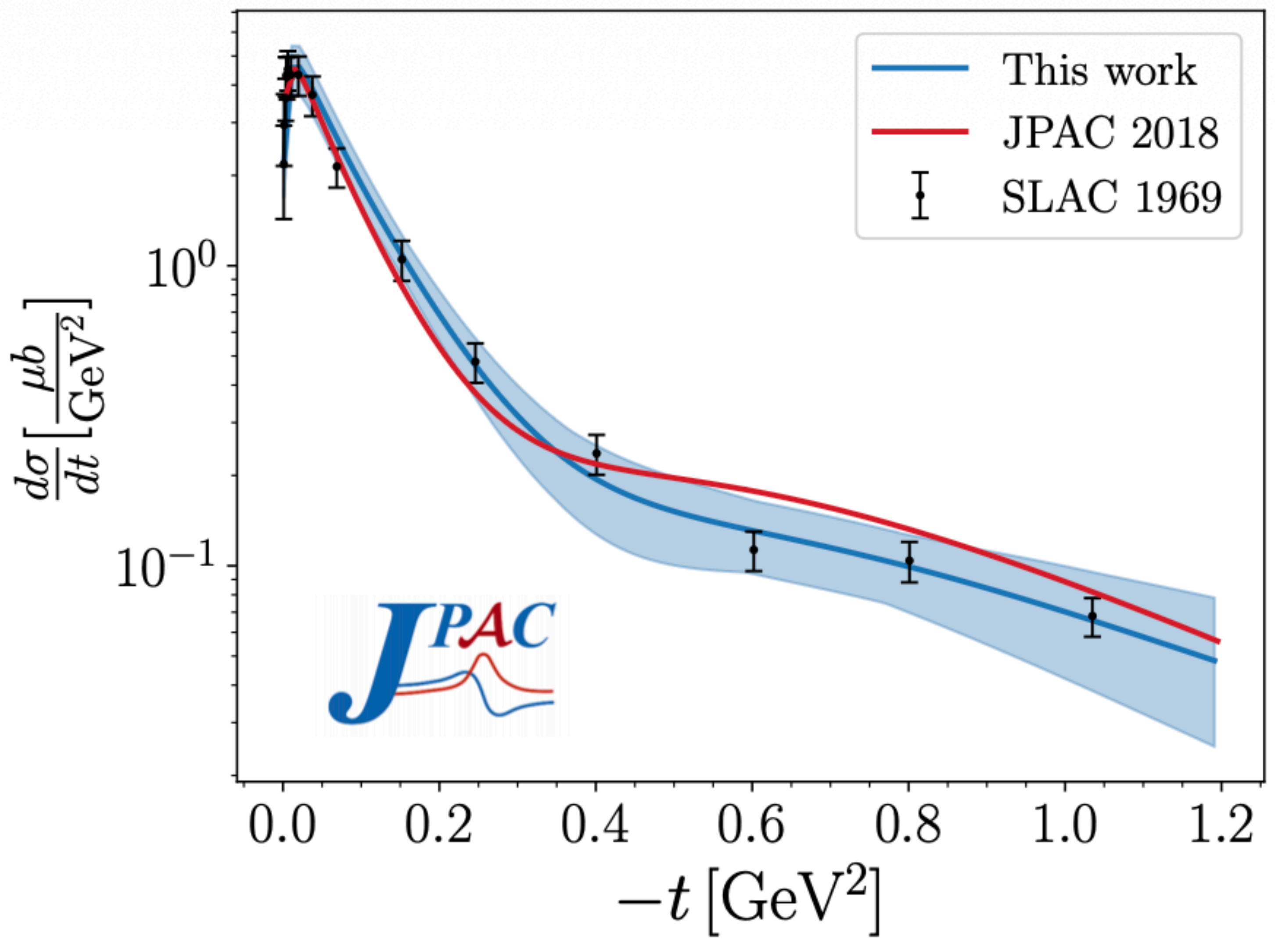
*(4 SDME or 1 diff. cross section + 3 normalized SDME)

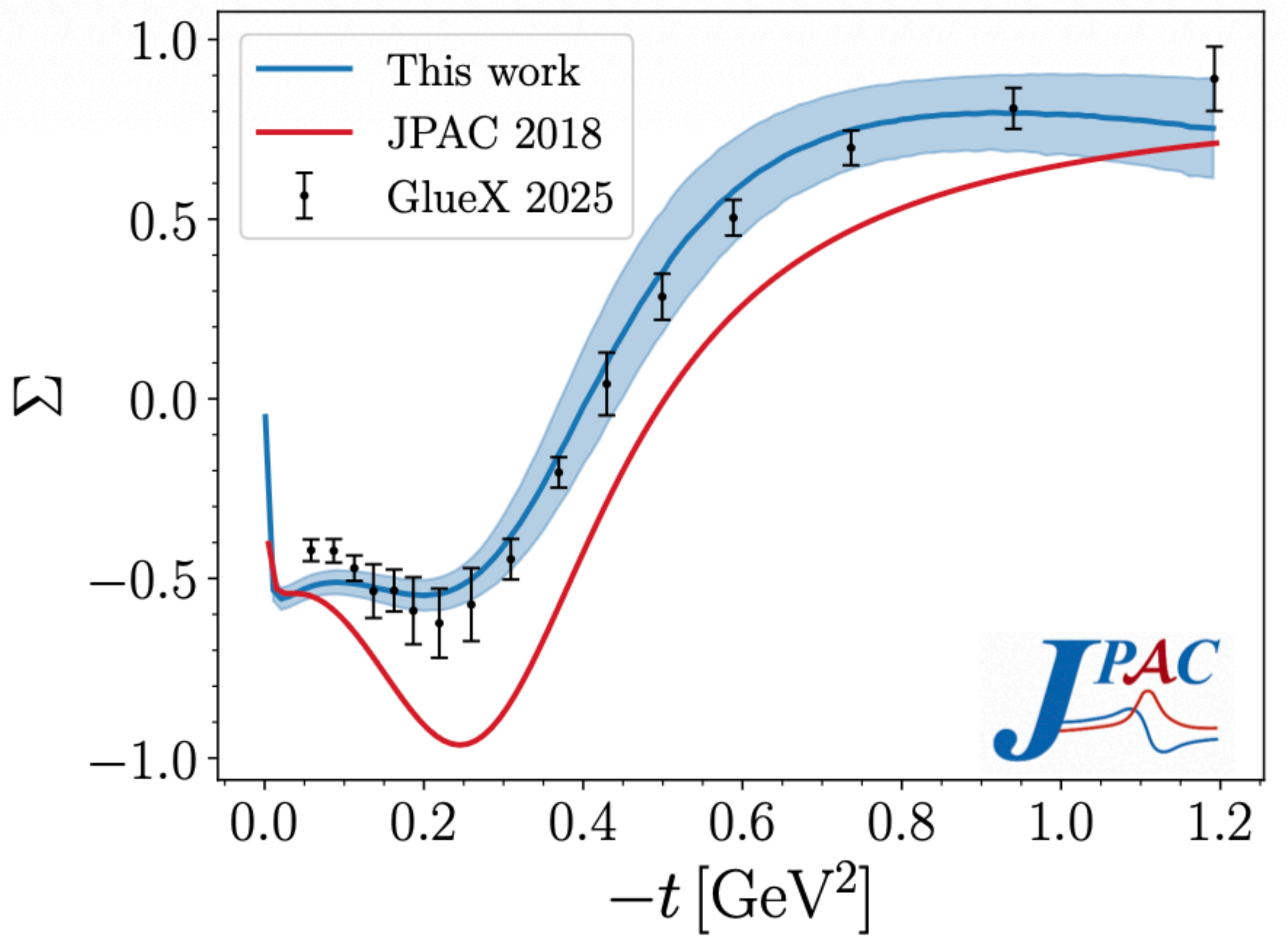
$\Delta^+(1232)$ Photoproduction @GlueX

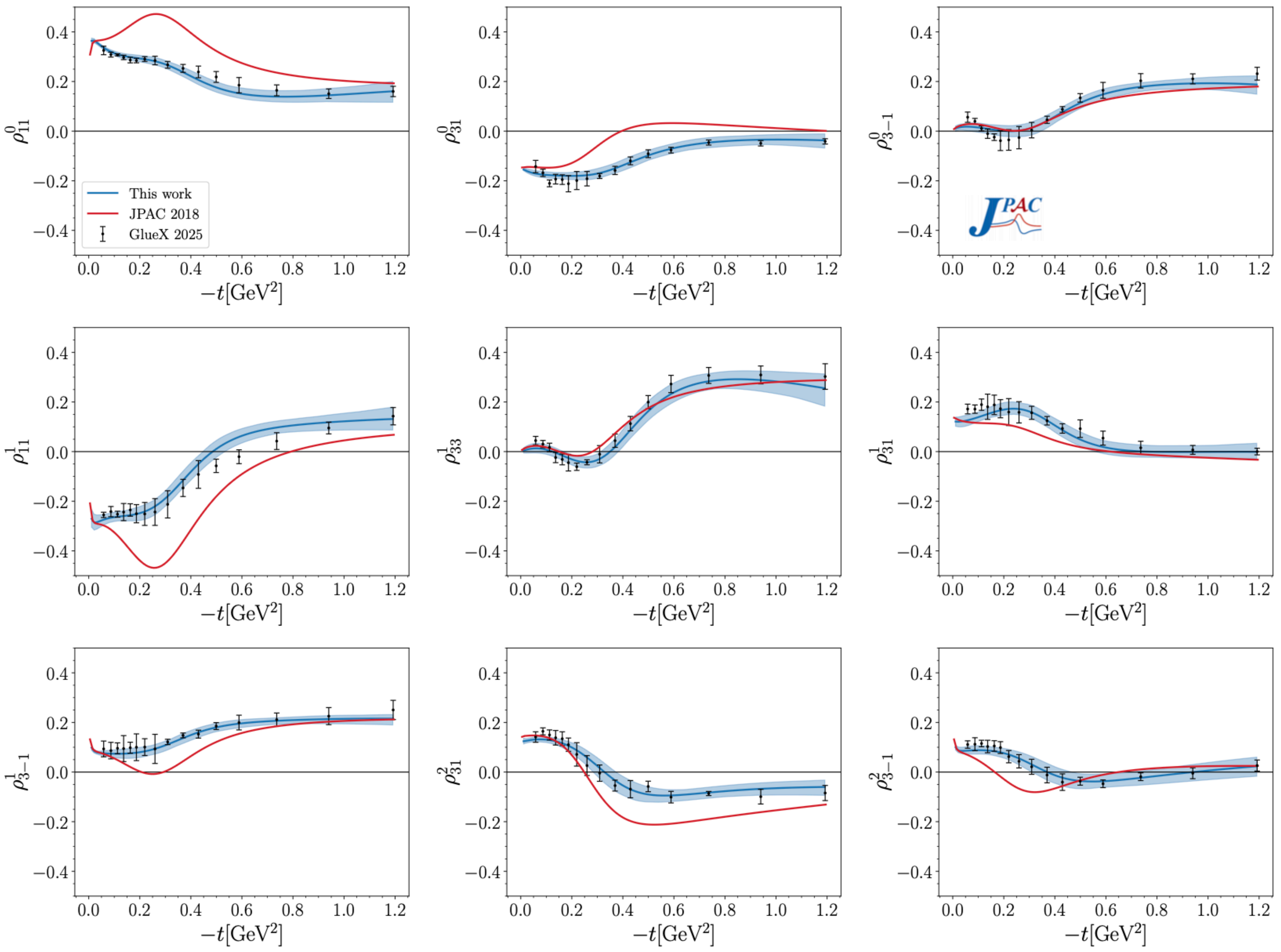
Shastry et al (JPAC) arXiv:2604.22719 & arXiv:2606.07917

Nys et al (JPAC) PLB779 (2018) 77

GlueX PLB863 (2025) 139368



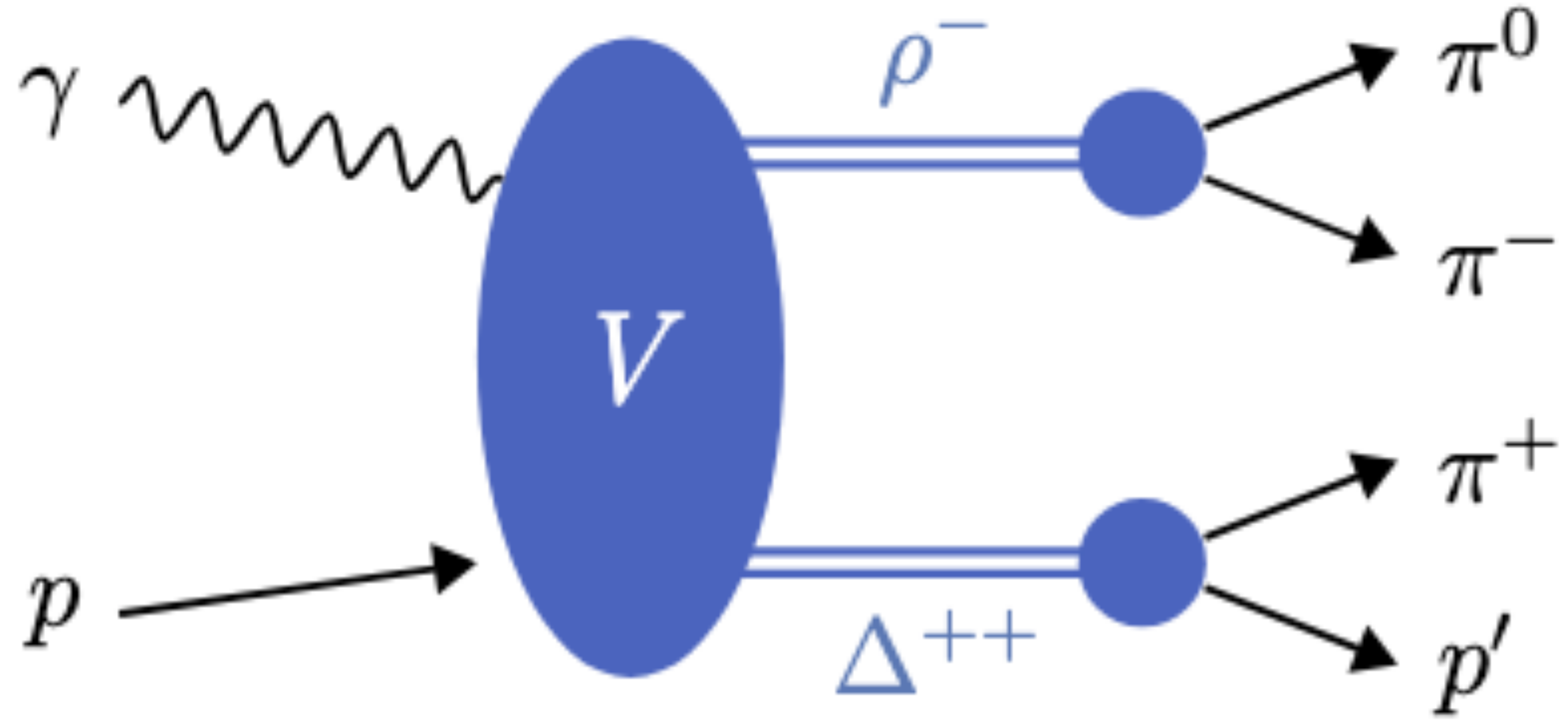




"Double Indices" Spin Density Matrix

Let's write the 2 decays:

$$A_{\lambda_\gamma,\lambda_1,\lambda_2} = \frac{1}{\sqrt{\pi}} \sum_{\ell} \sum_{\lambda_\Delta=-\frac{3}{2}}^{\frac{3}{2}} V^{\ell}_{\lambda_\gamma,m;\lambda_1,\lambda_\Delta}(s,t) F^{\ell}(m^2_{\pi\pi}) Y^{\ell}_{m}(\Omega_\pi) \tilde{F}_{\lambda_2}(m^2_{\pi p}) D^{\frac{3}{2}*}_{\lambda_\Delta,\lambda_2}(\Omega_p)$$



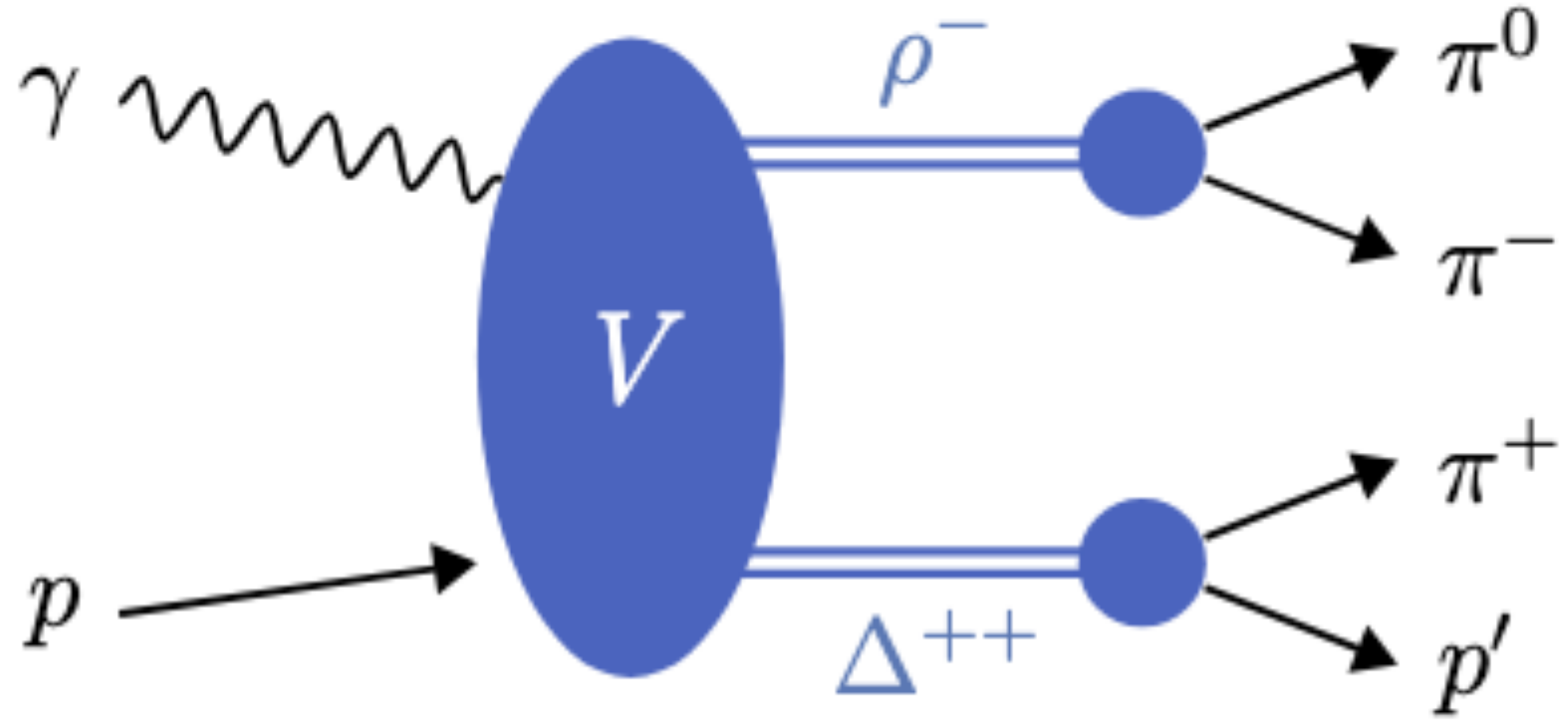
“Double Indices” Spin Density Matrix

Let’s write the 2 decays:

$$A_{\lambda_\gamma,\lambda_1,\lambda_2} = \frac{1}{\sqrt{\pi}} \sum_\ell \sum_{\lambda_\Delta=-\frac{3}{2}}^{\frac{3}{2}} V^\ell_{\lambda_\gamma,m;\lambda_1,\lambda_\Delta}(s,t) F^\ell(m^2_{\pi\pi}) Y^\ell_m(\Omega_\pi) \tilde{F}_{\lambda_2}(m^2_{\pi p}) D^{\frac{3}{2}*}_{\lambda_\Delta,\lambda_2}(\Omega_p)$$

The intensity is the squared:

$$I(\Omega) \propto \sum_{\substack{m,m' \\ \lambda_\Delta,\lambda'_\Delta}} D^{\frac{3}{2}*}_{\lambda_\Delta,\lambda_2}(\Omega_p) Y^1_m(\Omega)\ \rho_{\substack{mm' \\ \lambda_\Delta\lambda'_\Delta}}(s,t)\ Y^{1*}_{m'}(\Omega) D^{\frac{3}{2}}_{\lambda'_\Delta\lambda_2}(\Omega_p)$$



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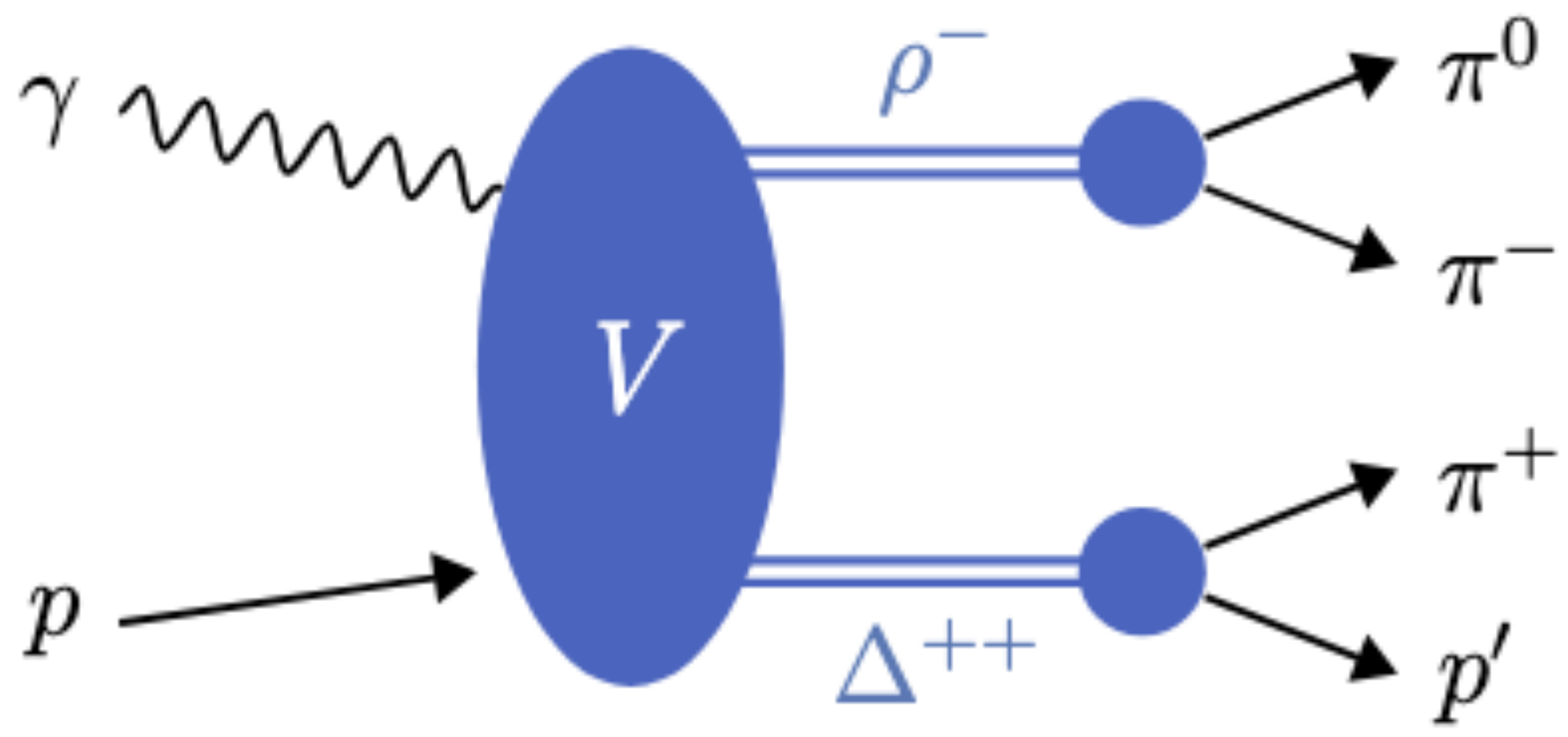

$$I(\Omega) \propto \sum_{\substack{m,m' \\ \lambda_\Delta,\lambda'_\Delta}} D^{\frac{3}{2}*}_{\lambda_\Delta,\lambda_2}(\Omega_p) Y^1_m(\Omega)\ \rho_{\substack{mm' \\ \lambda_\Delta\lambda'_\Delta}}(s,t)\ Y^{1*}_{m'}(\Omega) D^{\frac{3}{2}}_{\lambda'_\Delta\lambda_2}(\Omega_p)$$

$$\propto \sum_{\substack{m,m' \\ \lambda_\Delta,\lambda'_\Delta}} \rho_{\substack{mm' \\ \lambda_\Delta\lambda'_\Delta}}(s,t) \times \boxed{f_{\substack{m,m' \\ \lambda_\Delta,\lambda'_\Delta}}(\Omega_\pi,\Omega_p)}$$

Known angular functions

"Double Indices" Spin Density Matrix

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$$A_{\lambda_\gamma,\lambda_1,\lambda_2} = \frac{1}{\sqrt{\pi}} \sum_{\ell} \sum_{\lambda_\Delta=-\frac{3}{2}}^{\frac{3}{2}} V^{\ell}_{\lambda_\gamma,m;\lambda_1,\lambda_\Delta}(s,t) F^{\ell}(m^2_{\pi\pi}) Y^{\ell}_{m}(\Omega_\pi) \tilde{F}_{\lambda_2}(m^2_{\pi p}) D^{\frac{3}{2}*}_{\lambda_\Delta,\lambda_2}(\Omega_p)$$

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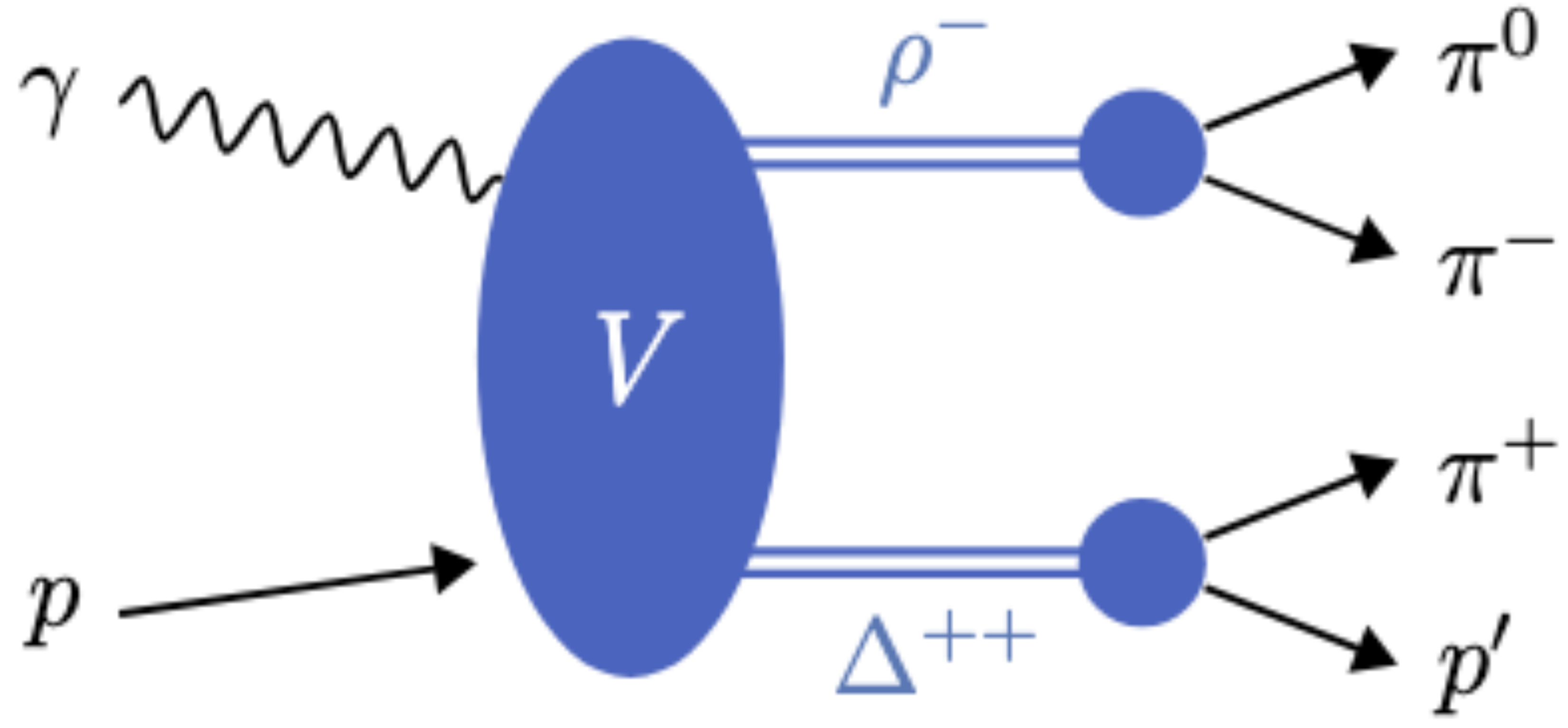
$$I(\Omega) \propto \sum_{\substack{m,m' \\ \lambda_\Delta,\lambda'_\Delta}} D^{\frac{3}{2}*}_{\lambda_\Delta,\lambda_2}(\Omega_p) Y^1_m(\Omega)\ \rho_{\substack{mm' \\ \lambda_\Delta\lambda'_\Delta}}(s,t)\ Y^{1*}_{m'}(\Omega) D^{\frac{3}{2}}_{\lambda'_\Delta\lambda_2}(\Omega_p)$$

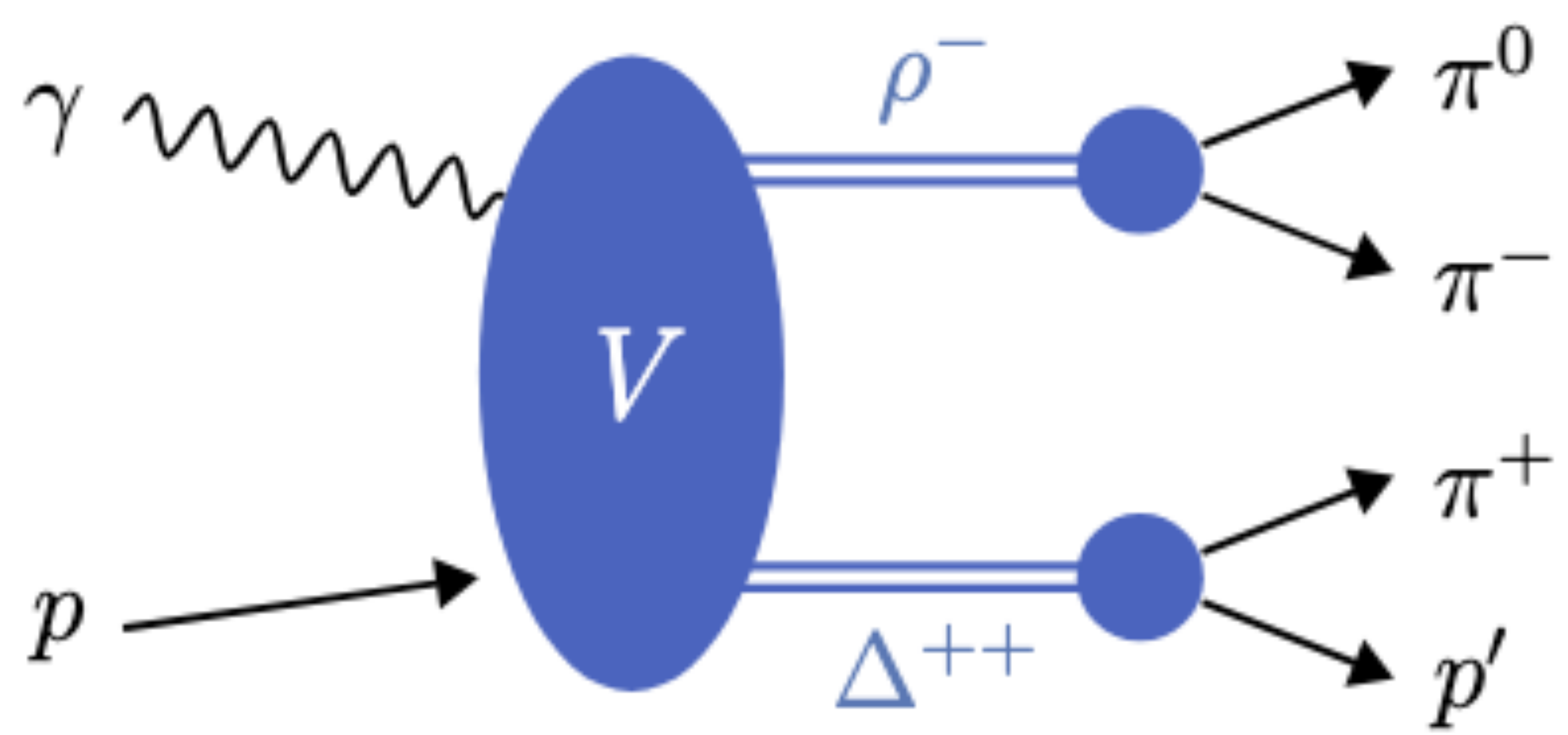
$$\propto \sum_{\substack{m,m' \\ \lambda_\Delta,\lambda'_\Delta}} \rho_{\substack{mm' \\ \lambda_\Delta\lambda'_\Delta}}(s,t) \times \boxed{f_{\substack{m,m' \\ \lambda_\Delta,\lambda'_\Delta}}(\Omega_\pi, \Omega_p)}$$

Known angular functions

Have known symmetry properties



“Double Indices” Spin Density Matrix



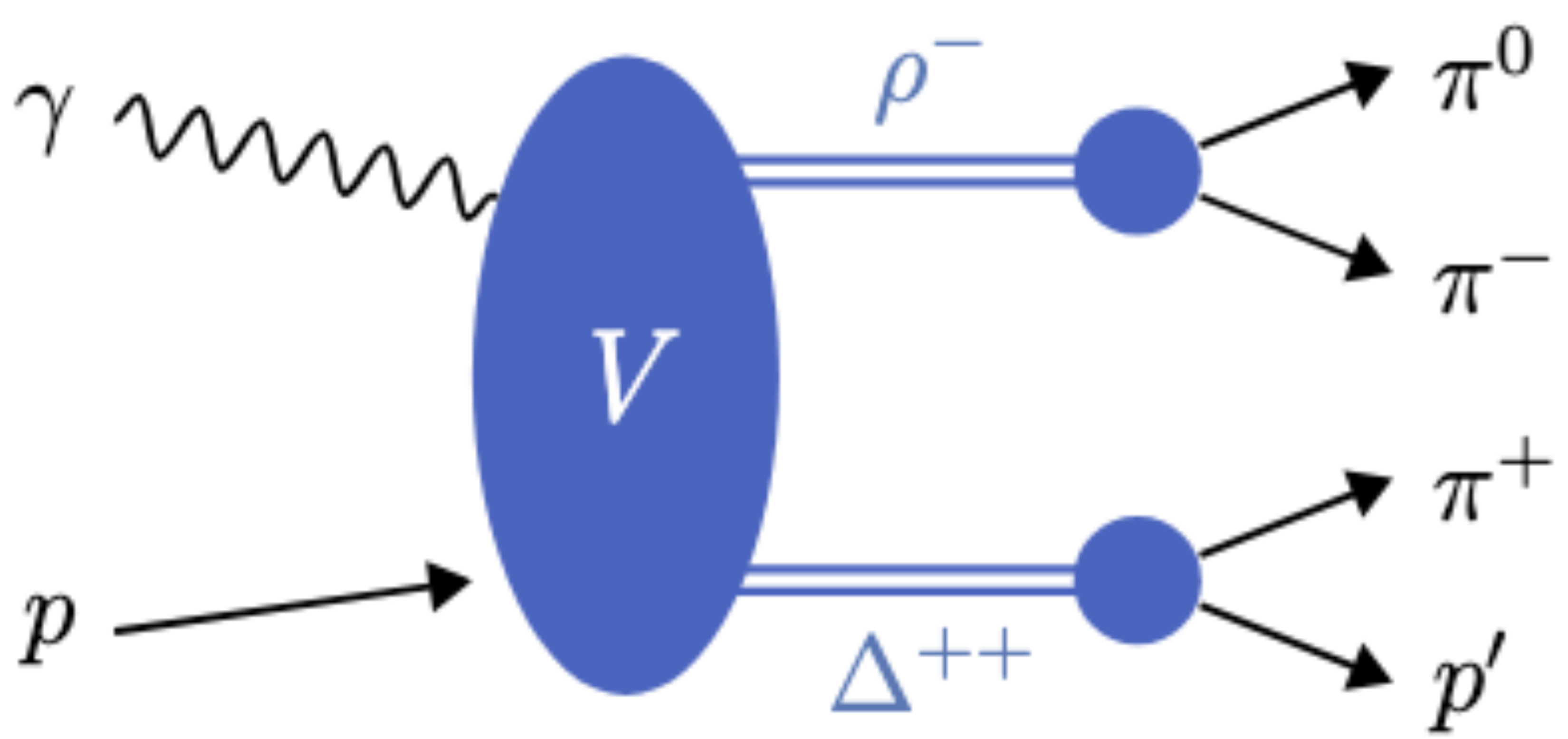
Unpolarized intensity:

$$
\begin{aligned}
W^0(\Omega_\pi, \Omega_p) = {} & \cos^2\theta_\pi \left[W^0_{00}(\Omega_p) - \overline{W}^0_{00}(\Omega_p)\right] + \sin^2\theta_\pi \left[W^0_{11}(\Omega_p) - \overline{W}^0_{11}(\Omega_p)\right] \\
& - \sin^2\theta_\pi \left(\cos 2\phi_\pi \left[W^0_{1-1}(\Omega_p) - \overline{W}^0_{1-1}(\Omega_p)\right] + \sin 2\phi_\pi\, \widetilde{W}^0_{1-1}(\Omega_p)\right) \\
& - \sqrt{2}\sin 2\theta_\pi \left(\cos\phi_\pi \left[W^0_{10}(\Omega_p) - \overline{W}^0_{10}(\Omega_p)\right] + \sin\phi_\pi\, \widetilde{W}^0_{10}(\Omega_p)\right)
\end{aligned}
$$

Auxiliary functions:

$$
\begin{aligned}
W^\alpha_{mm'}(\Omega) &= r^\alpha_{\substack{mm'\\33}} \sin^2\theta + r^\alpha_{\substack{mm'\\11}} \left(\frac{1}{3} + \cos^2\theta\right) \\
\overline{W}^\alpha_{mm'}(\Omega) &= \frac{2}{\sqrt{3}} \left[r^\alpha_{\substack{mm'\\31}} \cos\phi \sin 2\theta + r^\alpha_{\substack{mm'\\3-1}} \cos 2\phi \sin^2\theta \right] \\
\widetilde{W}^\alpha_{mm'}(\Omega) &= \frac{2}{\sqrt{3}} \left[\tilde{r}^\alpha_{\substack{mm'\\31}} \sin\phi \sin 2\theta + \tilde{r}^2_{\substack{mm'\\3-1}} \sin 2\phi \sin^2\theta \right]
\end{aligned}
$$

"Double Indices" Spin Density Matrix



Unpolarized intensity:

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\widetilde{W}^\alpha_{mm'}(\Omega) &= \frac{2}{\sqrt{3}} \left[\tilde{r}^{\alpha}_{\substack{mm'\\31}} \sin\phi \sin 2\theta + \tilde{r}^{2}_{\substack{mm'\\3-1}} \sin 2\phi \sin^2\theta \right]
\end{aligned}
$$

There are 20 coefficients to extract

$r^{00}_{11},\ r^{00}_{33},\ r^{00}_{31},\ r^{00}_{3-1}$

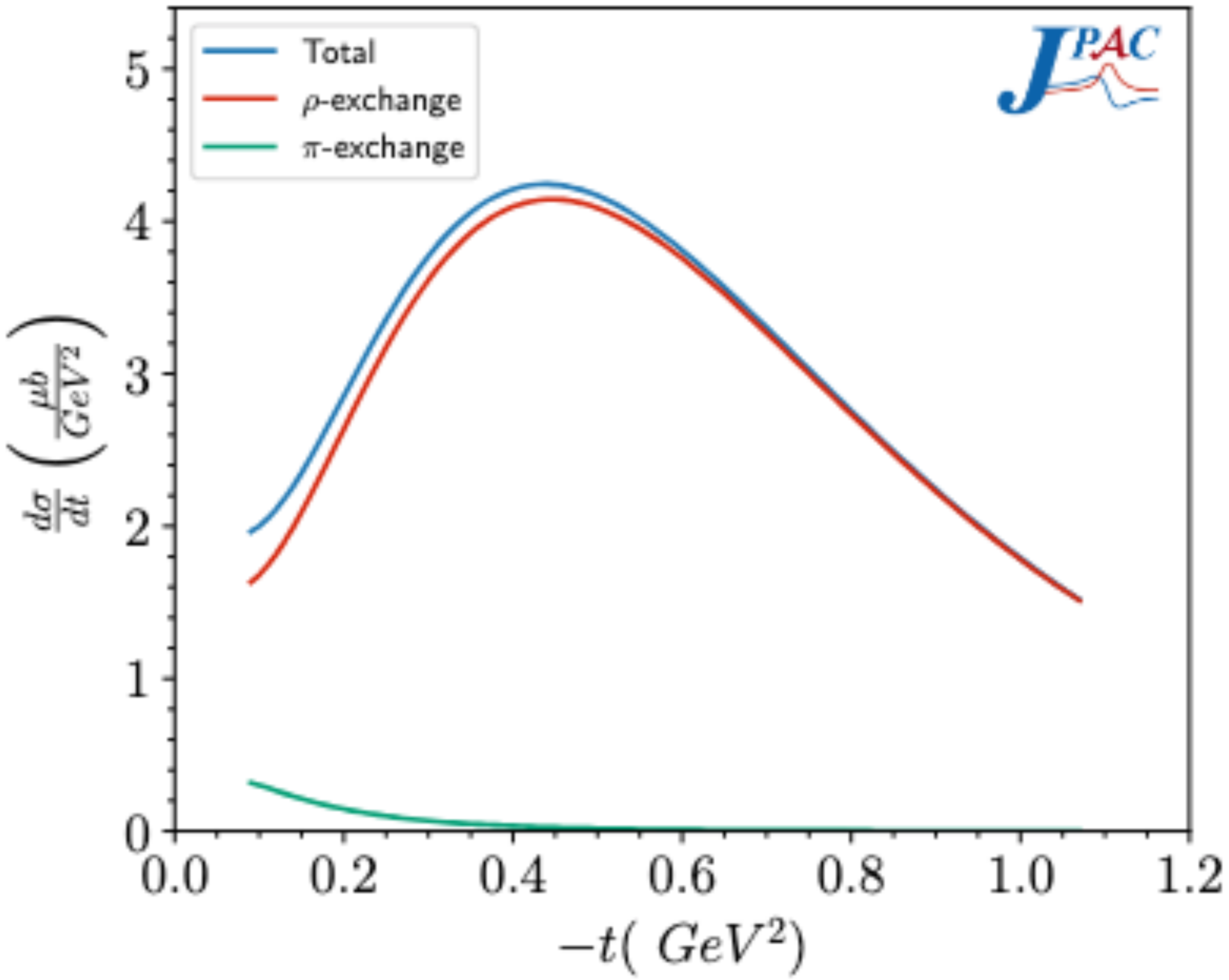
$r^{10}_{11},\ r^{10}_{33},\ r^{10}_{31},\ r^{10}_{3-1}$ $\quad$ $\tilde{r}^{10}_{31},\ \tilde{r}^{10}_{3-1}$

$r^{11}_{11},\ r^{11}_{33},\ r^{11}_{31},\ r^{11}_{3-1}$ $\quad$ $\tilde{r}^{1-1}_{31},\ \tilde{r}^{1-1}_{3-1}$

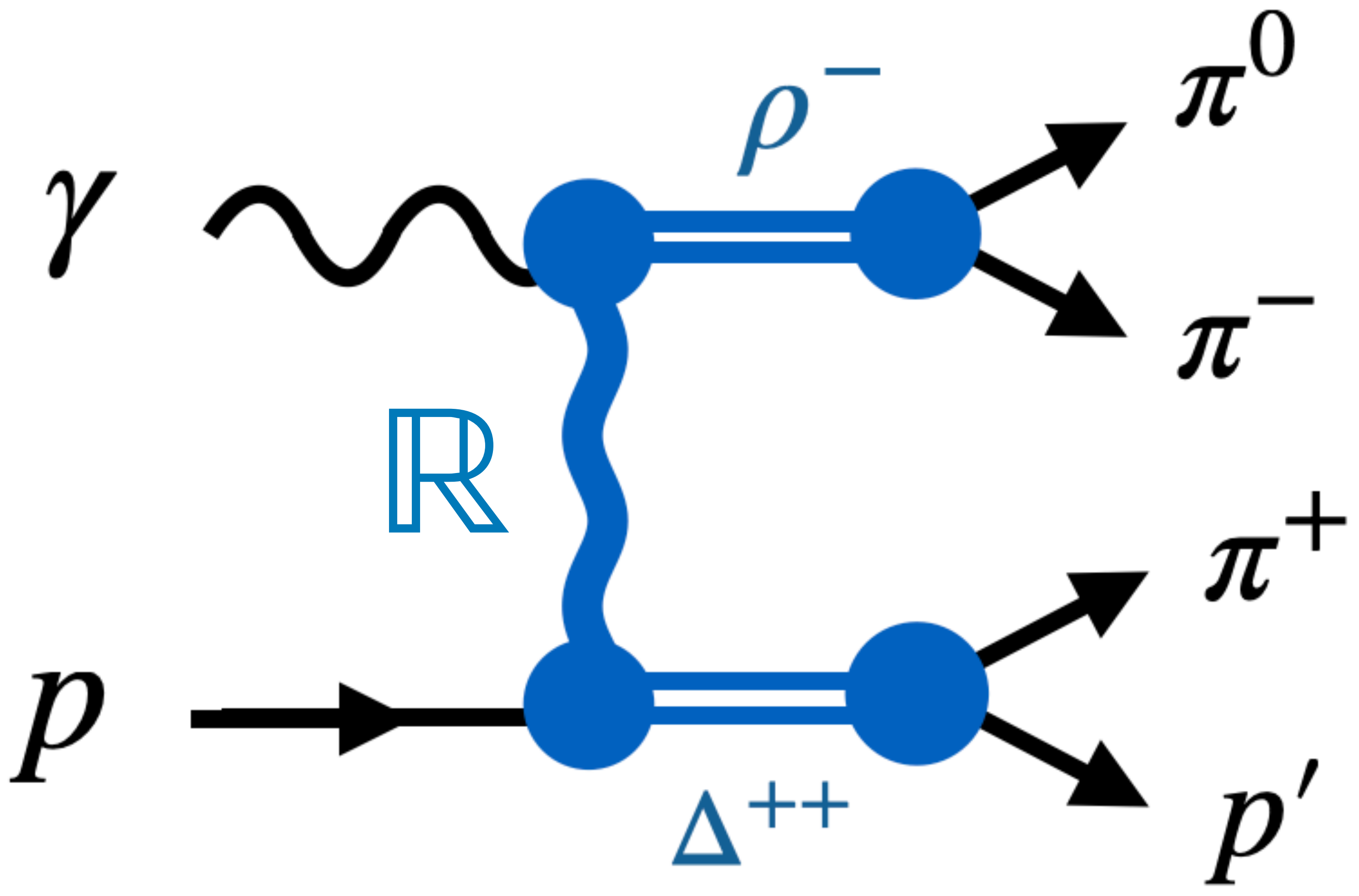
$r^{1-1}_{11},\ r^{1-1}_{33},\ r^{1-1}_{31},\ r^{1-1}_{3-1}$

A Preliminary Model

Regge exchanges includes: $\mathbb{R} = \rho, \pi$



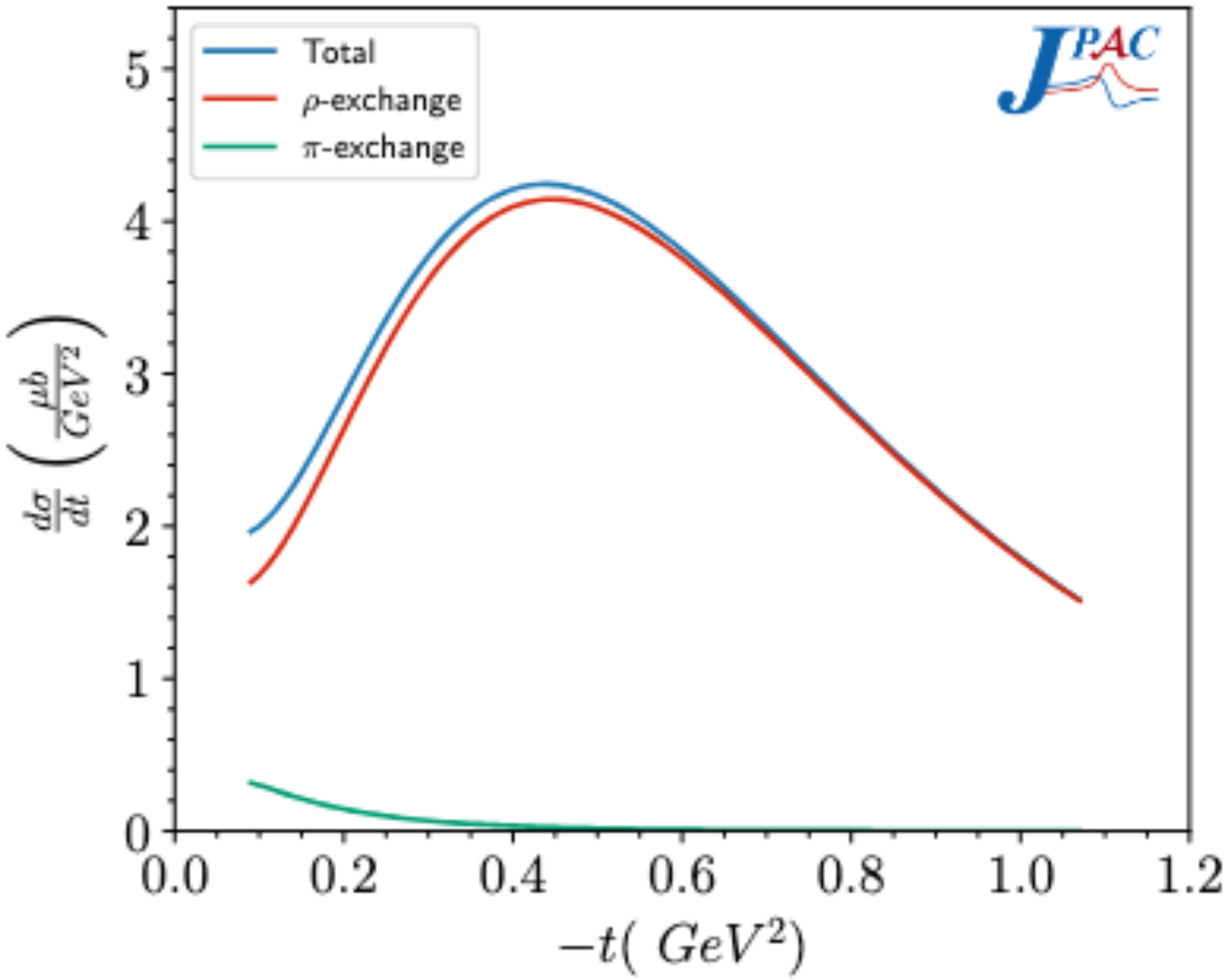
Courtesy of V. Shastry



Preliminary results indicate the dominance of the ρ (natural) exchange

A Preliminary Model

Regge exchanges includes: $\mathbb{R} = \rho, \pi$



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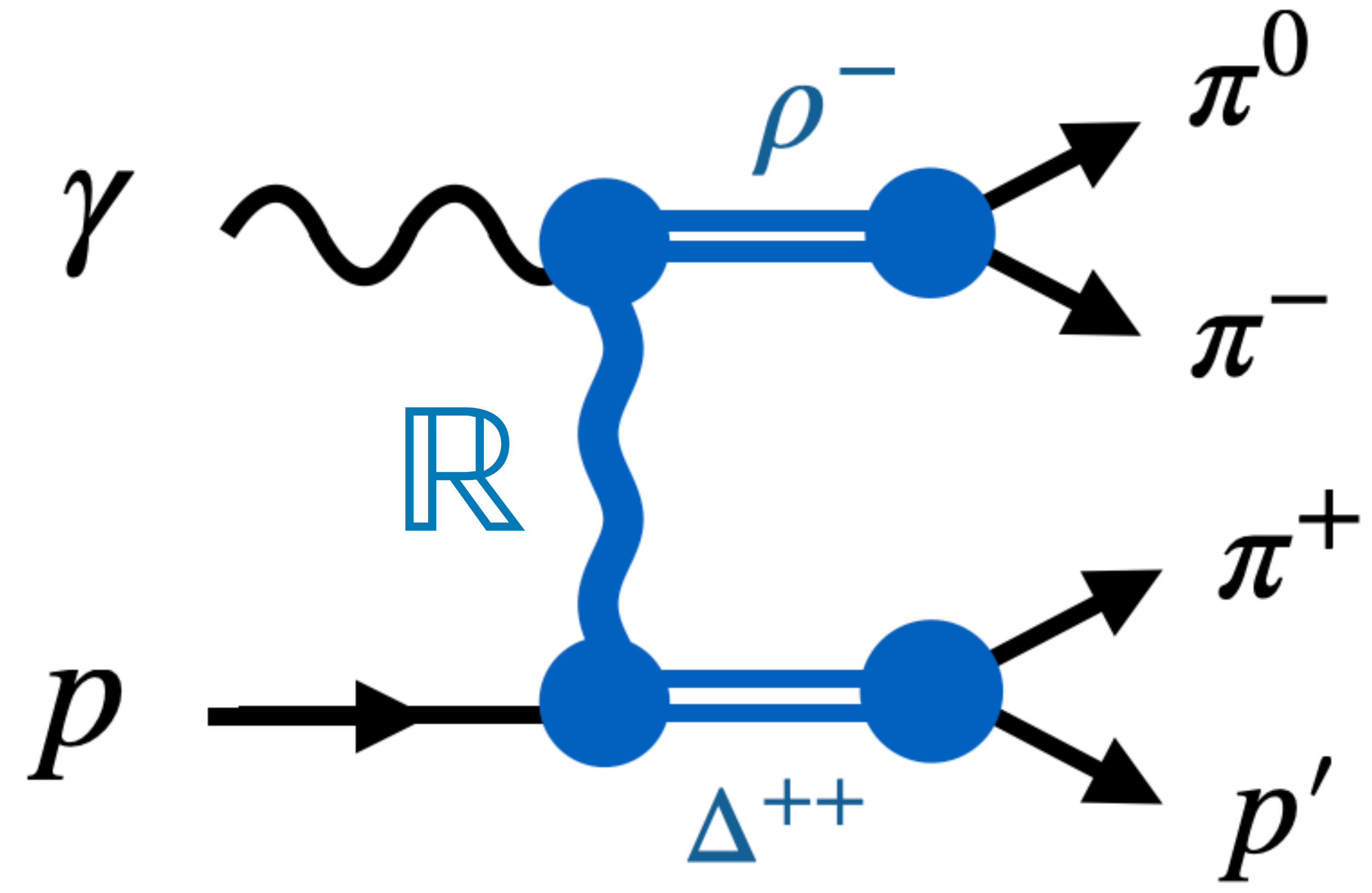


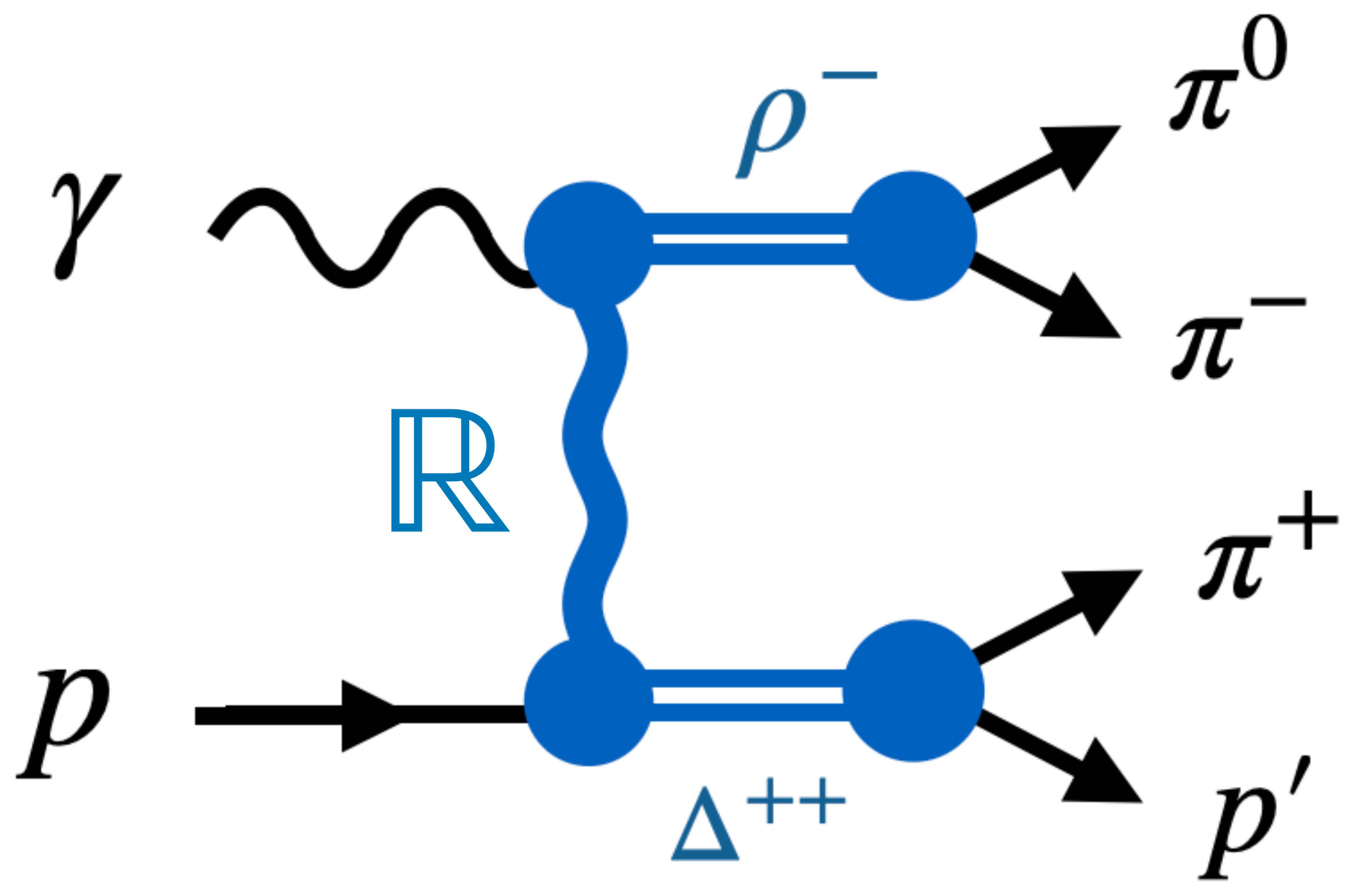
Preliminary results indicate the dominance of the ρ (natural) exchange

Let's assume production occurs via only natural exchange Reggeons

Factorization

Drastic approximation:

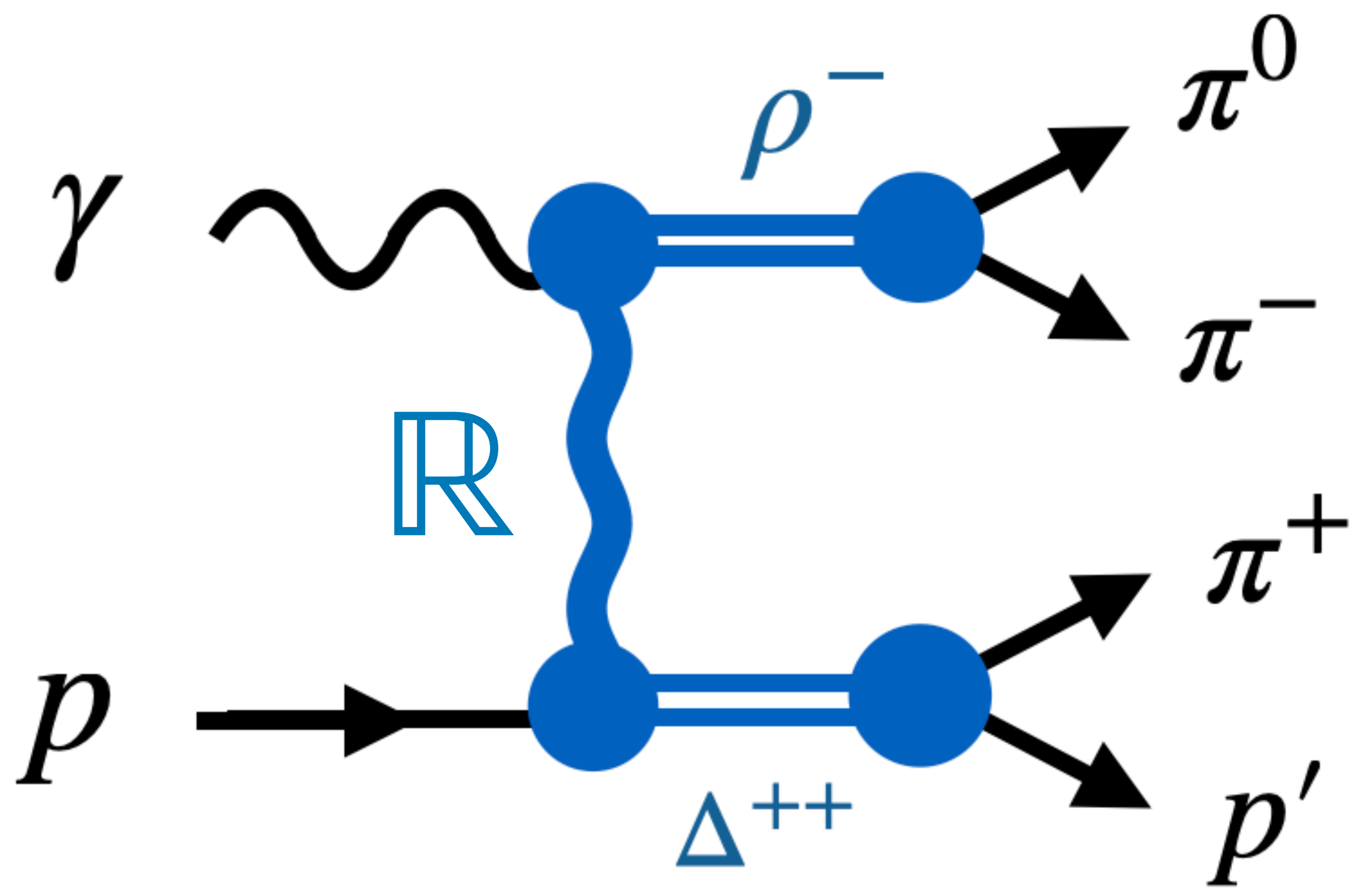
$$V_{\substack{\lambda_\gamma\lambda_\rho \\ \lambda_p\lambda_\Delta}}(s,t) = \beta_{\lambda_\gamma\lambda_\rho}(t) \times \gamma_{\lambda_p\lambda_\Delta}(t) \times f(s,t)$$



Factorization

Drastic approximation:

$$V_{\lambda_\gamma \lambda_\rho \atop \lambda_p \lambda_\Delta}(s,t) = \beta_{\lambda_\gamma\lambda_\rho}(t) \times \gamma_{\lambda_p\lambda_\Delta}(t) \times f(s,t)$$

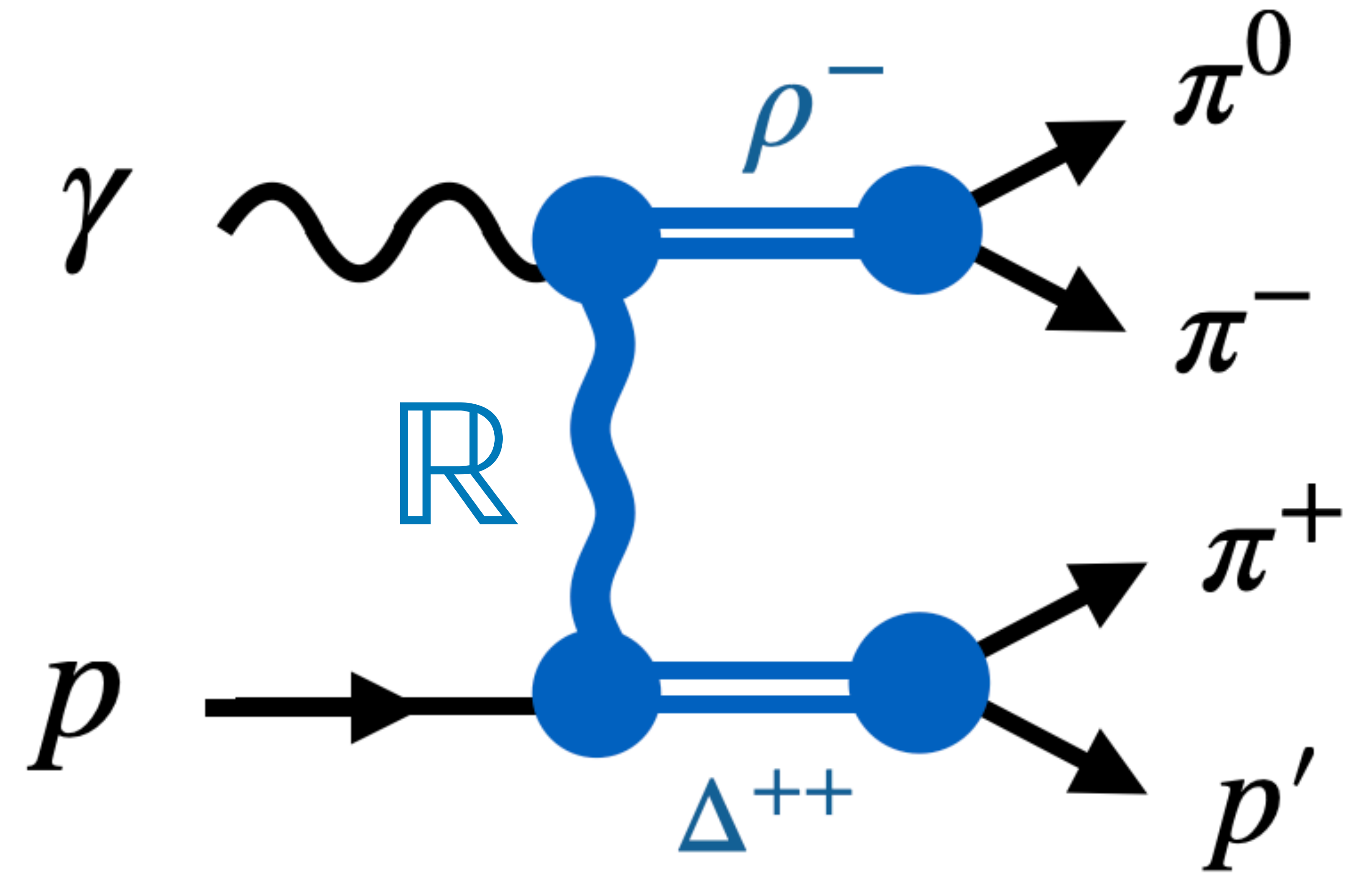


Consider only one type of
Regge exchange of naturality $\eta = P(-1)^J$

$$\beta_{-\lambda_\gamma -\lambda_\rho}(t) = \eta(-1)^{\lambda_\gamma - \lambda_\rho}\beta_{\lambda_\gamma\lambda_\rho}(t)$$

$$\gamma_{-\lambda_p -\lambda_\Delta}(t) = \eta(-1)^{\lambda_p + \lambda_\Delta}\gamma_{\lambda_p\lambda_\Delta}(t)$$

“Double Indices” Spin Density Matrix



Unpolarized intensity:

$$\begin{aligned} W^0(\Omega_\pi,\Omega_p) = {} & \cos^2\theta_\pi \left[W^0_{00}(\Omega_p) - \overline{W}^0_{00}(\Omega_p)\right] + \sin^2\theta_\pi \left[W^0_{11}(\Omega_p) - \overline{W}^0_{11}(\Omega_p)\right] \\ & - \sin^2\theta_\pi \left(\cos 2\phi_\pi \left[W^0_{1-1}(\Omega_p) - \overline{W}^0_{1-1}(\Omega_p)\right] + \cancel{\sin 2\phi_\pi\, \widetilde{W}^0_{1-1}(\Omega_p)}\right) \\ & - \sqrt{2}\sin 2\theta_\pi \left(\cos\phi_\pi \left[W^0_{10}(\Omega_p) - \overline{W}^0_{10}(\Omega_p)\right] + \cancel{\sin\phi_\pi\, \widetilde{W}^0_{10}(\Omega_p)}\right) \end{aligned}$$

There are ~~20~~ coefficients to extract

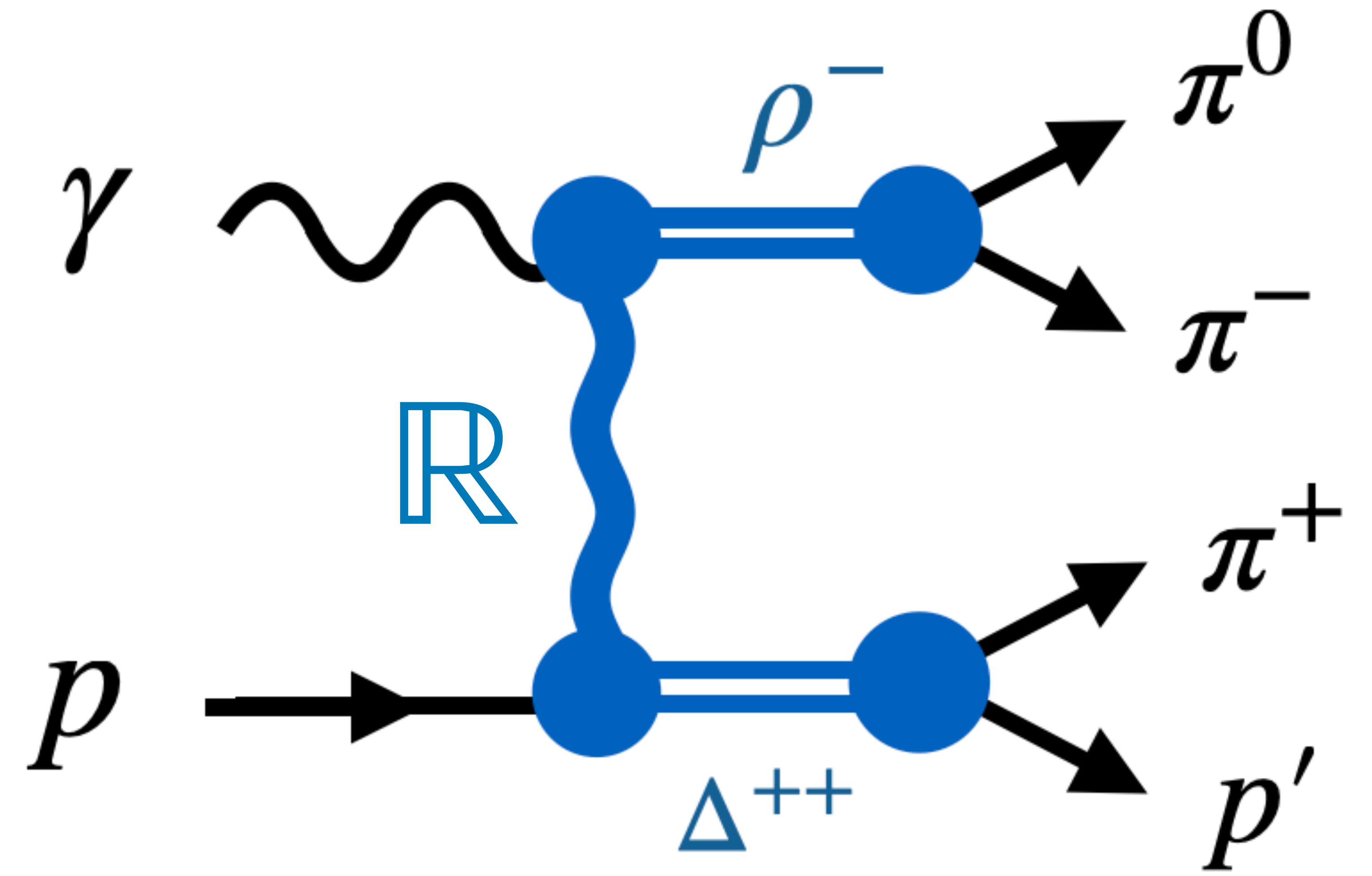
$r^{11}_{00},\ r^{33}_{00},\ r^{31}_{00},\ r^{3-1}_{00}$

$r^{11}_{10},\ r^{33}_{10},\ r^{31}_{10},\ r^{3-1}_{10}$ $\quad \cancel{\tilde r^{31}_{10}},\ \cancel{\tilde r^{3-1}_{10}}$

$r^{11}_{11},\ r^{33}_{11},\ r^{31}_{11},\ r^{3-1}_{11}$ $\quad \cancel{\tilde r^{31}_{1-1}},\ \cancel{\tilde r^{3-1}_{1-1}}$

$r^{11}_{1-1},\ r^{33}_{1-1},\ r^{31}_{1-1},\ r^{3-1}_{1-1}$

“Double Indices” Spin Density Matrix



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&- \sin^2\theta_\pi \left(\cos 2\phi_\pi \left[W^0_{1-1}(\Omega_p) - \overline{W}^0_{1-1}(\Omega_p)\right] + \sin 2\phi_\pi \cancel{\widetilde{W}^0_{1-1}}(\Omega_p)\right) \\
&- \sqrt{2}\sin 2\theta_\pi \left(\cos\phi_\pi \left[W^0_{10}(\Omega_p) - \overline{W}^0_{10}(\Omega_p)\right] + \sin\phi_\pi \cancel{\widetilde{W}^0_{10}}(\Omega_p)\right)
\end{aligned}
$$

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$$r_{\substack{00\\11}},\ r_{\substack{00\\33}},\ r_{\substack{00\\31}},\ r_{\substack{00\\3-1}}$$

$$r_{\substack{10\\11}},\ r_{\substack{10\\33}},\ r_{\substack{10\\31}},\ r_{\substack{10\\3-1}} \qquad \cancel{\tilde{r}_{\substack{10\\31}}},\ \cancel{\tilde{r}_{\substack{10\\3-1}}}$$

$$r_{\substack{11\\11}},\ r_{\substack{11\\33}},\ r_{\substack{11\\31}},\ r_{\substack{11\\3-1}} \qquad \cancel{\tilde{r}_{\substack{1-1\\31}}},\ \cancel{\tilde{r}_{\substack{1-1\\3-1}}}$$

$$r_{\substack{1-1\\11}},\ r_{\substack{1-1\\33}},\ r_{\substack{1-1\\31}},\ r_{\substack{1-1\\3-1}}$$

The 20 = 4 + 16 parameters reduce to 4+4:

$$r^{\alpha}_{\substack{mm'\\\lambda\lambda'}} = r^{\rho,\alpha}_{mm'} \times r^{\Delta}_{\lambda\lambda'}$$

$$r^\rho_{00},\ r^\rho_{11},\ r^\rho_{10},\ r^\rho_{1-1}$$

$$r^\Delta_{00},\ r^\Delta_{11},\ r^\Delta_{10},\ r^\Delta_{1-1}$$

Intensity with Linearly Polarized Beam

Including the photon spin density matrix:

$$I(\Phi, \Omega_\pi, \Omega_p) = \underset{20}{W^0(\Omega_\pi, \Omega_p)} - P_\gamma \underset{20}{W^1(\Omega_\pi, \Omega_p)} \cos 2\Phi - P_\gamma \underset{16}{W^2(\Omega_\pi, \Omega_p)} \sin 2\Phi$$

Total numbers of parameters: 56

Intensity with Linearly Polarized Beam

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$$I(\Phi, \Omega_\pi, \Omega_p) = \underbrace{W^0(\Omega_\pi, \Omega_p)}_{20} - P_\gamma \underbrace{W^1(\Omega_\pi, \Omega_p)}_{20} \cos 2\Phi - P_\gamma \underbrace{W^2(\Omega_\pi, \Omega_p)}_{16} \sin 2\Phi$$

Total numbers of parameters: 56

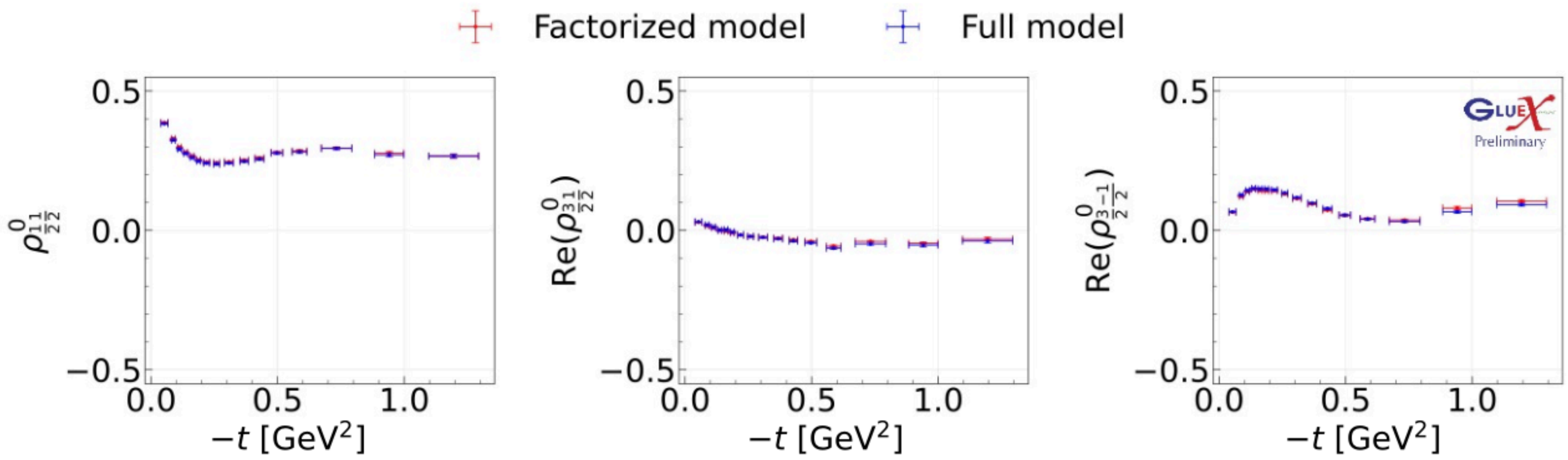
In the factorization approximation

$$I(\Phi, \Omega_\pi, \Omega_p) \simeq \left[\underbrace{W^0_\rho(\Omega_\pi)}_{4} - P_\gamma \underbrace{W^1_\rho(\Omega_\pi)}_{4} \cos 2\Phi - P_\gamma \underbrace{W^2_\rho(\Omega_\pi)}_{2} \sin 2\Phi \right] \underbrace{W_\Delta(\Omega_p)}_{4}$$

Total numbers of parameters: 14

GlueX Results on $\vec{\gamma} p \to \rho^- \Delta^{++}$

Δ^{++} – SDMEs



→Overall good agreement between full model and factorized model

MESON Kraków - B6 | Niklas Herrmann (herrmann@jlab.org) | June 29, 2026

GlueX Results on $\vec{\gamma} p \to \rho^- \Delta^{++}$

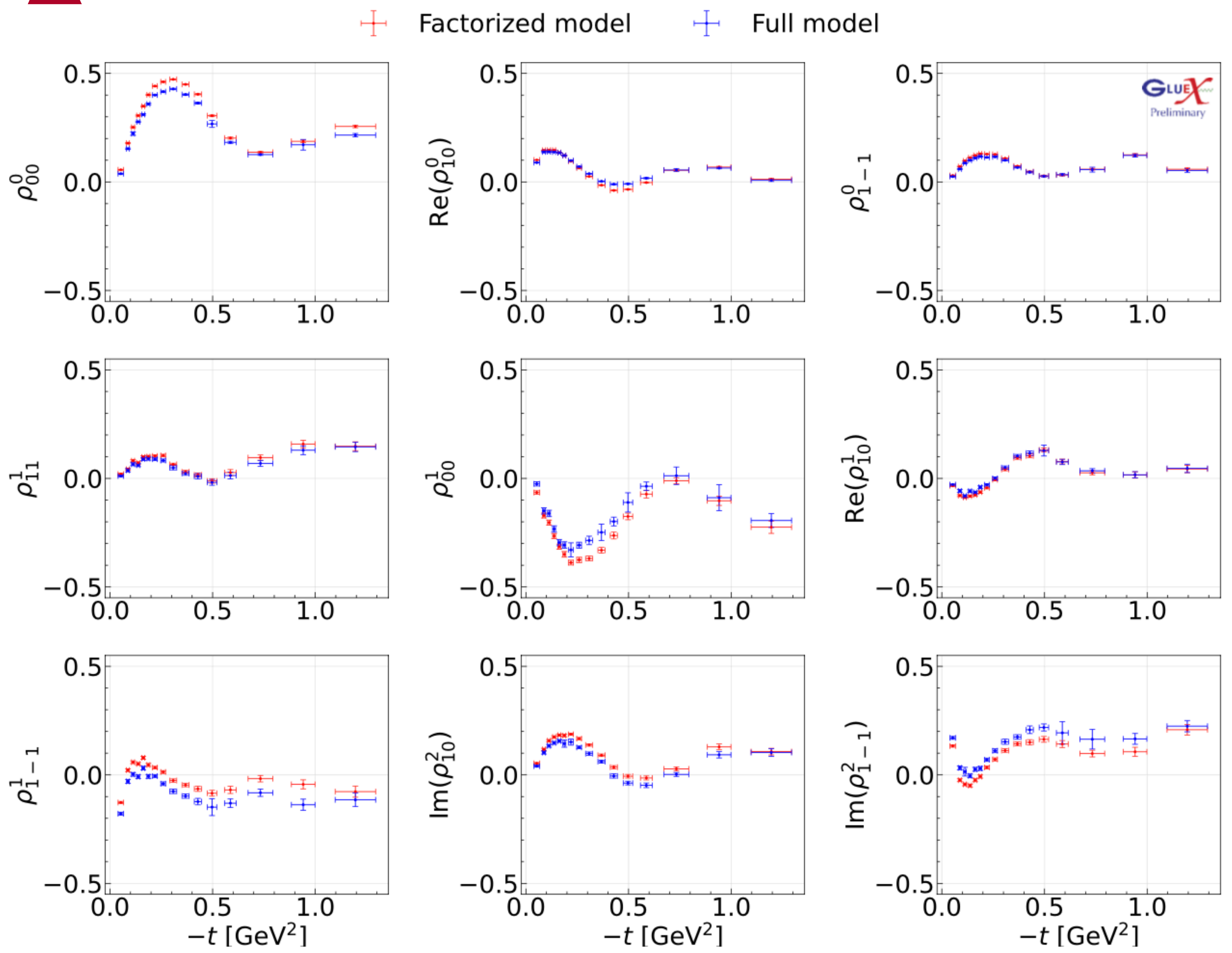
Very good agreement!

The intensity factorizes

Is it because there is only one naturally exchange?

Is it because there is only one naturally exchange?

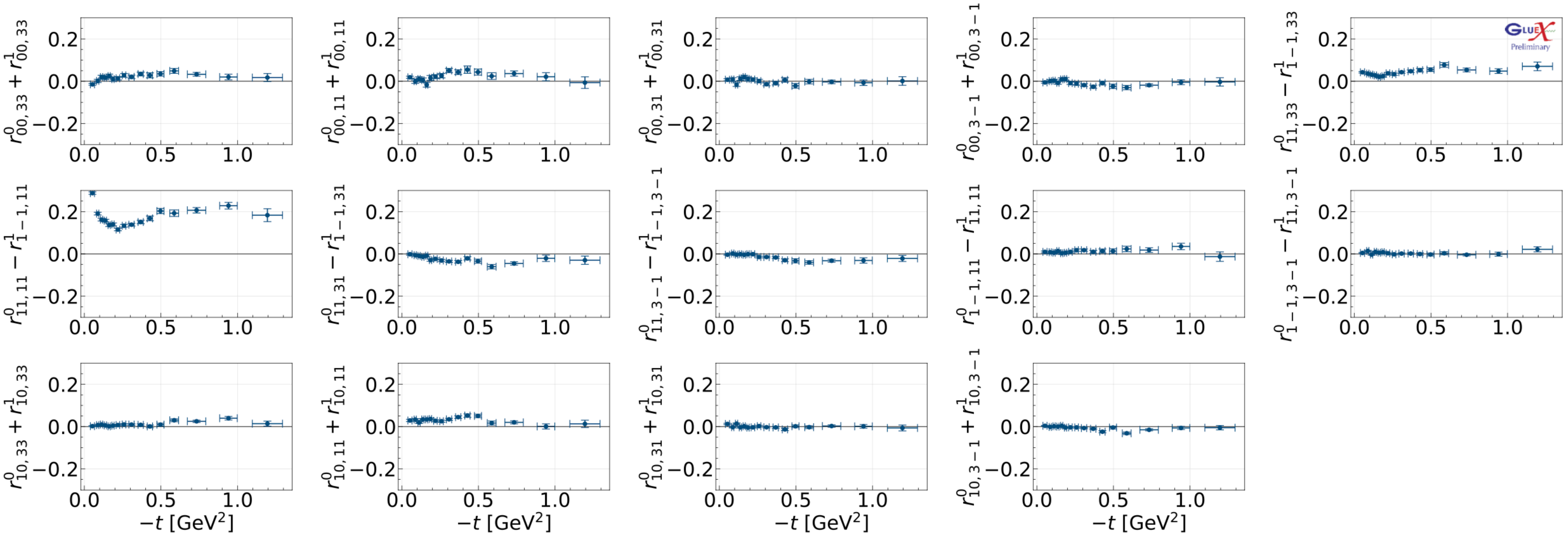
ρ^- − SDMEs



MESON Kraków - B6 | Niklas Herrmann (herrmann@jlab.org) | June 29, 2026

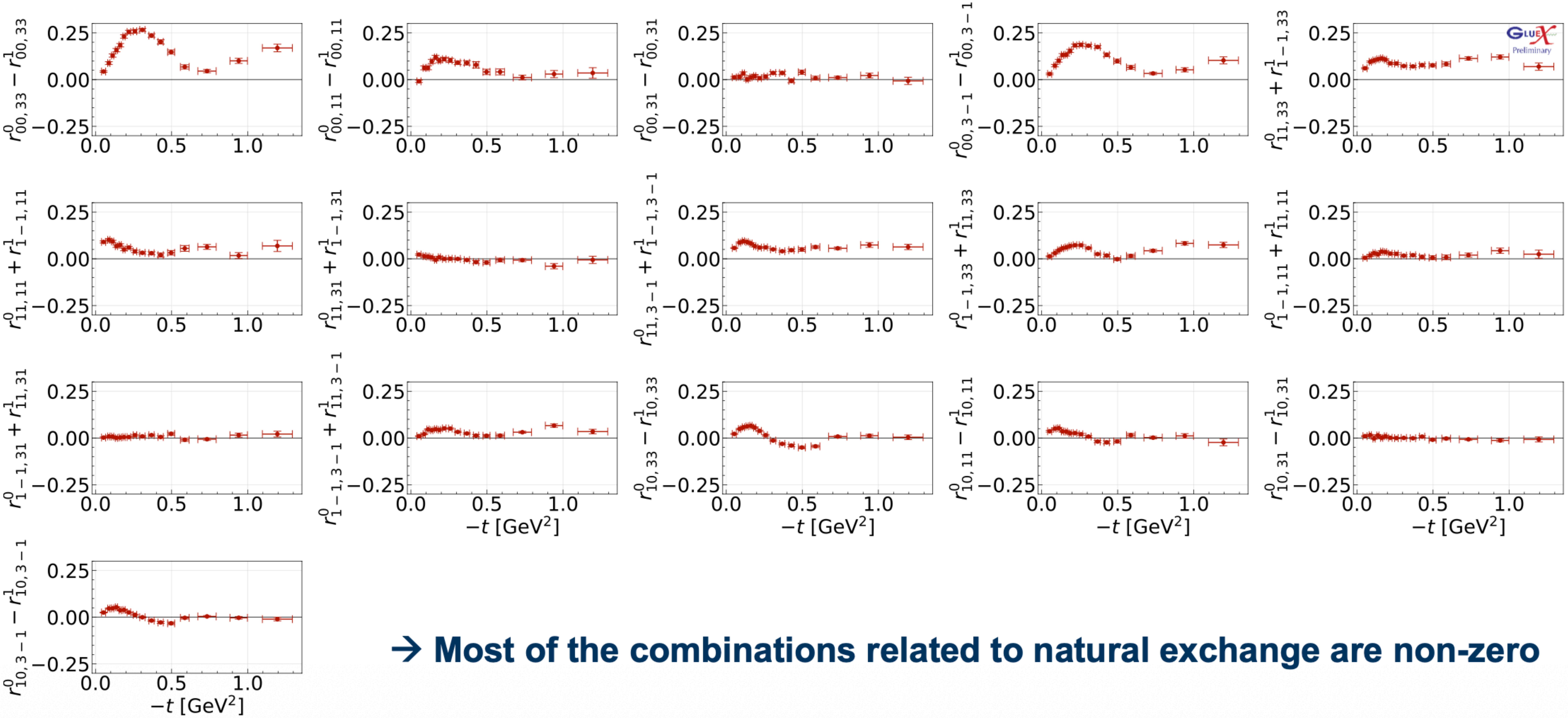
GlueX Results on $\vec{\gamma} p \to \rho^- \Delta^{++}$

Unnatural exchange small and compatible with pion exchange



→ Small unnatural exchange contributions

GlueX Results on $\vec{\gamma} p \to \rho^- \Delta^{++}$

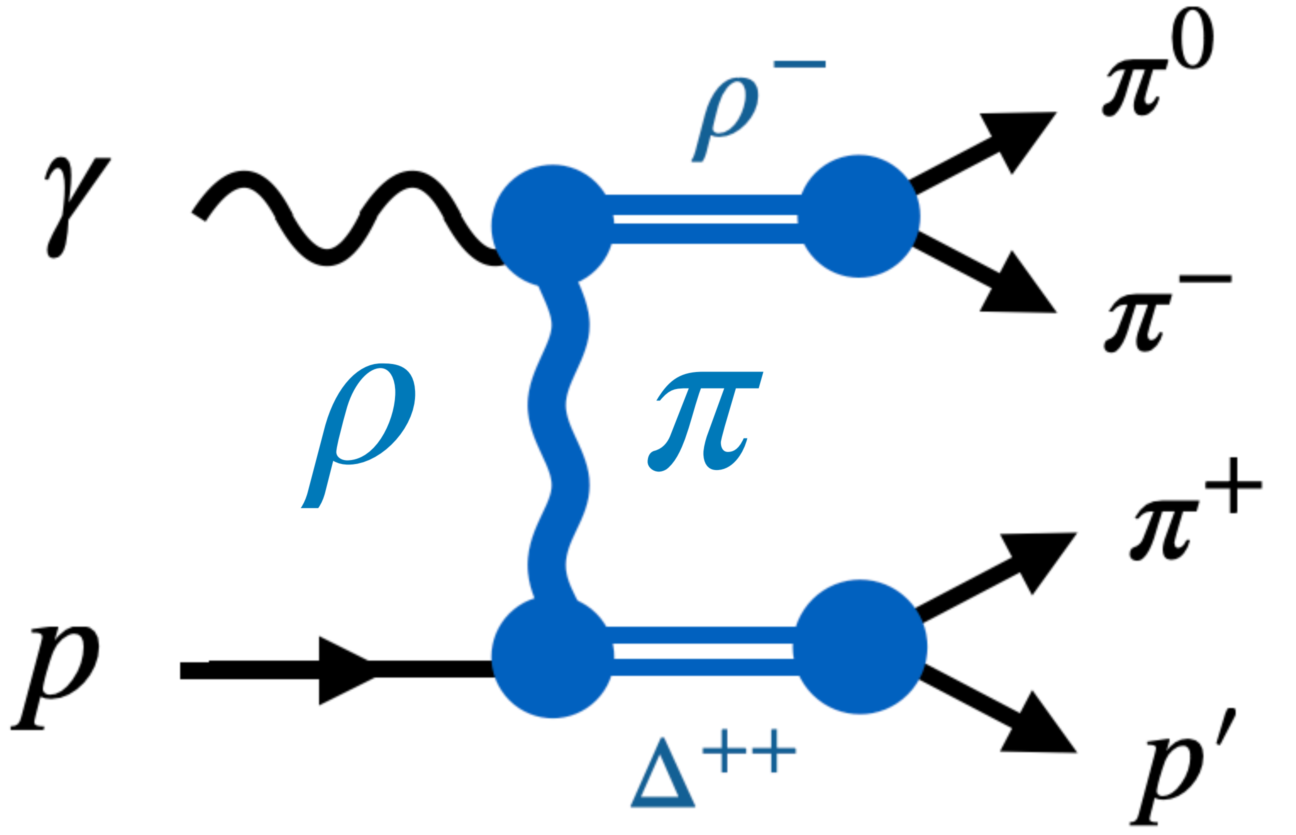


→ **Most of the combinations related to natural exchange are non-zero**

Summary:

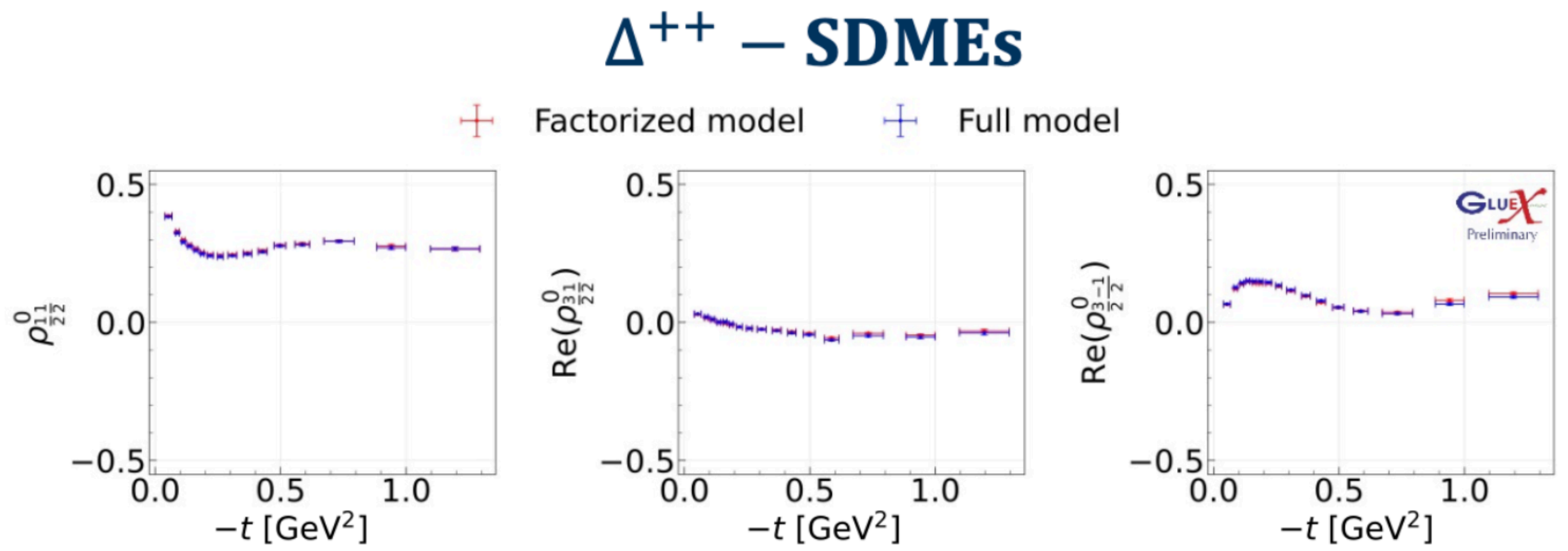
$\gamma p \to b_1^- \pi^0 \Delta^{++}$ Ultimate goal $\pi_1 \to b_1 \pi$

$\gamma p \to \rho^- \Delta^{++}$ Ongoing analysis

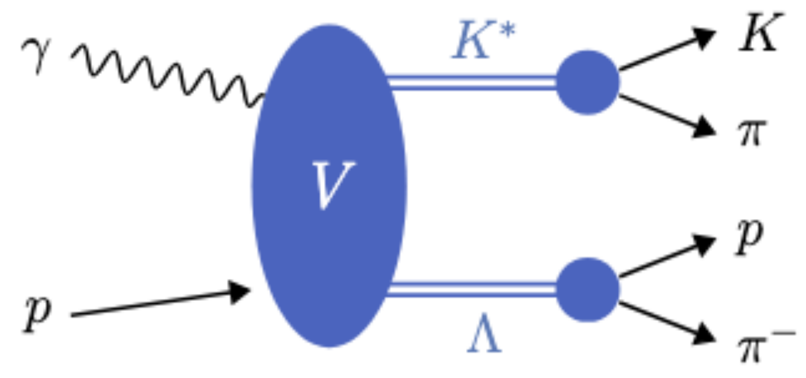


Experimental observation of factorization

Explanation (to be confirmed):
only one Regge exchange dominates



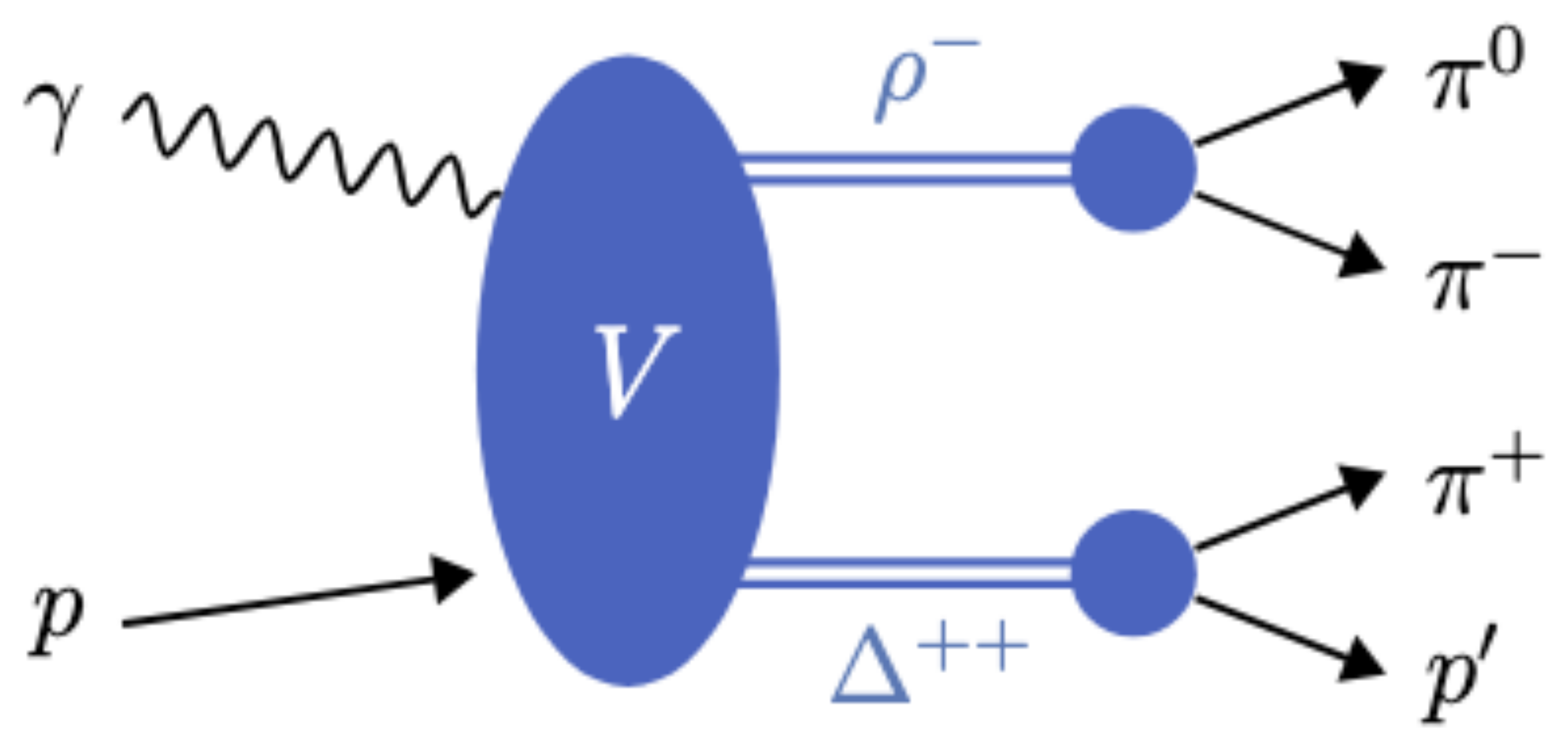
Similar observation in $\gamma p \to K^* \Lambda$ cf H. Li's talk at Meson 2026



JPAC and GlueX are building a comprehensive understanding of meson/baryon photoproduction, channel by channel

Backup Slides

“Double Indices” Spin Density Matrix



Unpolarized intensity:

$$\begin{aligned}
W^0(\Omega_\pi, \Omega_p) = {} & \cos^2\theta_\pi \left[W^0_{00}(\Omega_p) - \overline{W}^0_{00}(\Omega_p)\right] + \sin^2\theta_\pi \left[W^0_{11}(\Omega_p) - \overline{W}^0_{11}(\Omega_p)\right] \\
& - \sin^2\theta_\pi \left(\cos 2\phi_\pi \left[W^0_{1-1}(\Omega_p) - \overline{W}^0_{1-1}(\Omega_p)\right] + \sin 2\phi_\pi \, \widetilde{W}^0_{1-1}(\Omega_p)\right) \\
& - \sqrt{2}\sin 2\theta_\pi \left(\cos\phi_\pi \left[W^0_{10}(\Omega_p) - \overline{W}^0_{10}(\Omega_p)\right] + \sin\phi_\pi \, \widetilde{W}^0_{10}(\Omega_p)\right)
\end{aligned}$$

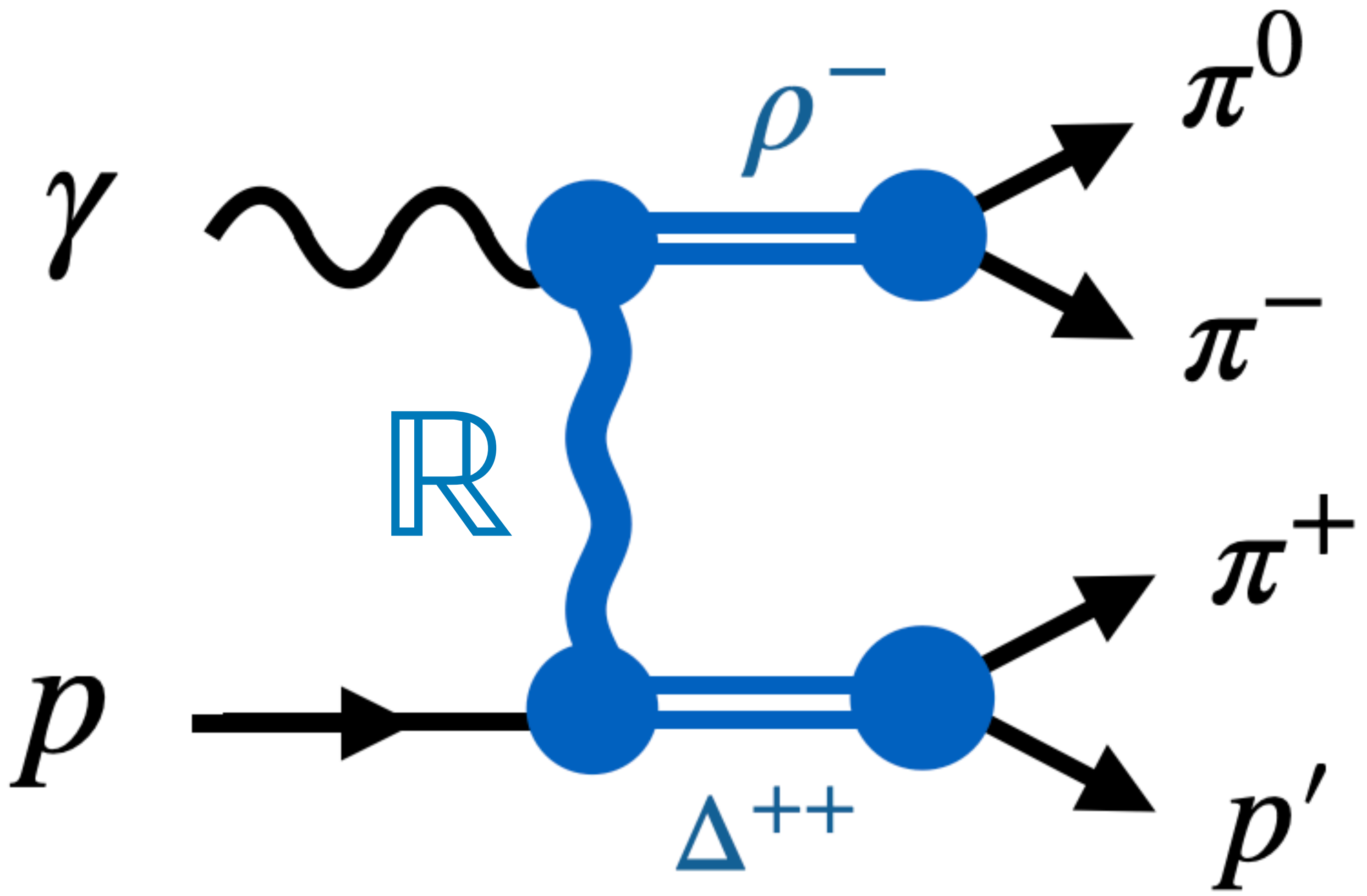
Auxiliary functions:

$$\begin{aligned}
W^\alpha_{mm'}(\Omega) &= r^\alpha_{\substack{mm'\\33}} \sin^2\theta + r^\alpha_{\substack{mm'\\11}} \left(\frac{1}{3} + \cos^2\theta\right) \\
\overline{W}^\alpha_{mm'}(\Omega) &= \frac{2}{\sqrt{3}} \left[r^\alpha_{\substack{mm'\\31}} \cos\phi \sin 2\theta + r^\alpha_{\substack{mm'\\3-1}} \cos 2\phi \sin^2\theta \right] \\
\widetilde{W}^\alpha_{mm'}(\Omega) &= \frac{2}{\sqrt{3}} \left[\tilde{r}^\alpha_{\substack{mm'\\31}} \sin\phi \sin 2\theta + \tilde{r}^2_{\substack{mm'\\3-1}} \sin 2\phi \sin^2\theta \right]
\end{aligned}$$

Reflectivity components:

$$r^0_{\substack{mm'\\\lambda\lambda'}} \pm r^1_{\substack{m-m'\\\lambda\lambda'}}$$

Factorized Unpolarized Intensity



Unpolarized intensity factorize to

$$W^0(\Omega_\pi, \Omega_p) = W^0_\rho(\Omega_\pi) \times W^0_\Delta(\Omega_p)$$

$$W^0_\rho(\Omega) = r^{\rho 0}_{00} \cos^2\theta + r^{\rho 0}_{11} \sin^2\theta - r^{\rho 0}_{1-1} \cos 2\phi \sin^2\theta - \sqrt{2} r^{\rho 0}_{10} \cos\phi \sin 2\theta$$

$$W^0_\Delta(\Omega) = r^{\Delta 0}_{11}\left(\frac{1}{3} + \cos^2\theta\right) + r^{\Delta 0}_{33} \sin^2\theta - \frac{2}{\sqrt{3}} r^{\Delta 0}_{3-1} \cos 2\phi \sin^2\theta - \frac{2}{\sqrt{3}} r^{\Delta 0}_{31} \cos\phi \sin 2\theta$$

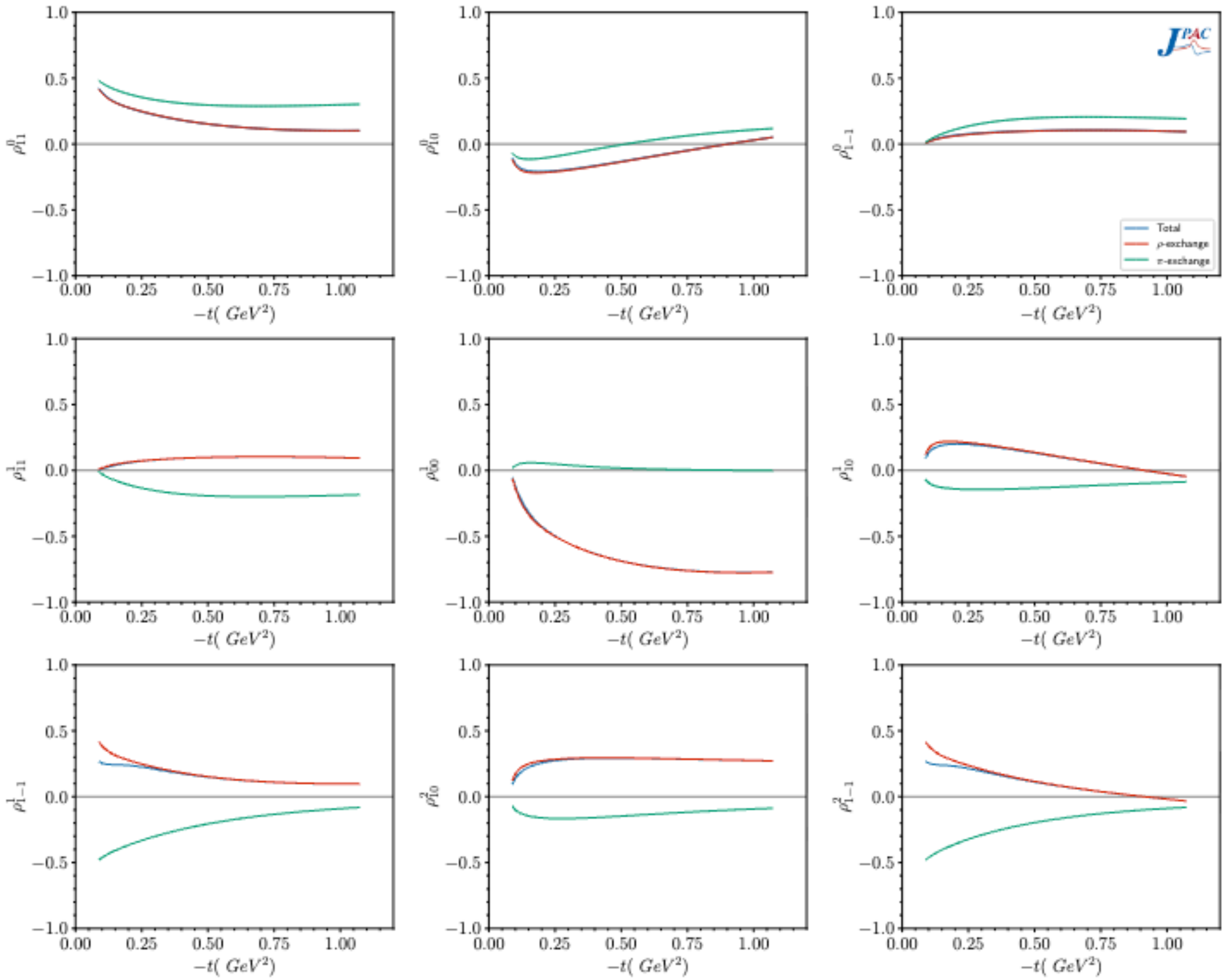
$W^0_{\rho,\Delta}(\Omega)$ are the standard decay functions for P-waves

A Preliminary Model

Green is only Pion exchange

Red is only Rho exchange

Blue = Red is Rho+Pi exchange



Factorized Intensity

Assuming that the production amplitudes factorize:

$$I(\Phi, \Omega_\pi, \Omega_p) = \Big[\underset{4}{W^0_\rho(\Omega_\pi)} - \underset{4}{P_\gamma W^1_\rho(\Omega_\pi)}\cos 2\Phi - \underset{2}{P_\gamma W^2_\rho(\Omega_\pi)}\sin 2\Phi\Big] \underset{4}{W_\Delta(\Omega_p)}$$

The two of the three $W^\alpha_\rho(\Omega)$ are identical:

$$W^{0,1}_\rho(\Omega) = r^{\rho 0,1}_{00}\cos^2\theta + r^{\rho 0,1}_{11}\sin^2\theta - r^{\rho 0,1}_{1-1}\cos 2\phi \sin^2\theta - \sqrt{2} r^{\rho 0,1}_{10}\cos\phi \sin 2\theta$$

$$W^2_\rho(\Omega) = r^{\rho 2}_{1-1}\sin 2\phi \sin^2\theta + \sqrt{2} r^{\rho 2}_{10}\sin\phi \sin 2\theta$$

The Δ^{++} decays factorizes and $W_\Delta(\Omega)$ is:

$$W_\Delta(\Omega) = r^\Delta_{11}\left(\frac{1}{3} + \cos^2\theta\right) + r^\Delta_{33}\sin^2\theta - \frac{2}{\sqrt{3}} r^\Delta_{3-1}\cos 2\phi \sin^2\theta - \frac{2}{\sqrt{3}} r^\Delta_{31}\cos\phi \sin 2\theta$$

Intensity with Linearly Polarized Beam

Including the photon spin density matrix:

$$I(\Phi, \Omega_\pi, \Omega_p) = W^0(\Omega_\pi, \Omega_p) - P_\gamma W^1(\Omega_\pi, \Omega_p)\cos 2\Phi - P_\gamma W^2(\Omega_\pi, \Omega_p)\sin 2\Phi$$

$W^0(\Omega_\pi, \Omega_p)$ includes 20 parameters

$W^1(\Omega_\pi, \Omega_p)$ includes 20 parameters

$W^2(\Omega_\pi, \Omega_p)$ includes 16 parameters

Complete intensity includes 56 parameters

Factorized version:

$W_\rho^{0,1}(\Omega_\pi)$ includes 4+4 parameters

$W_\rho^2(\Omega_\pi)$ includes 2 parameters

$W_\Delta(\Omega_p)$ includes 4 parameters

Factorized intensity includes 14 parameters

$\vec{\gamma} p \to K\Lambda(1520)$

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