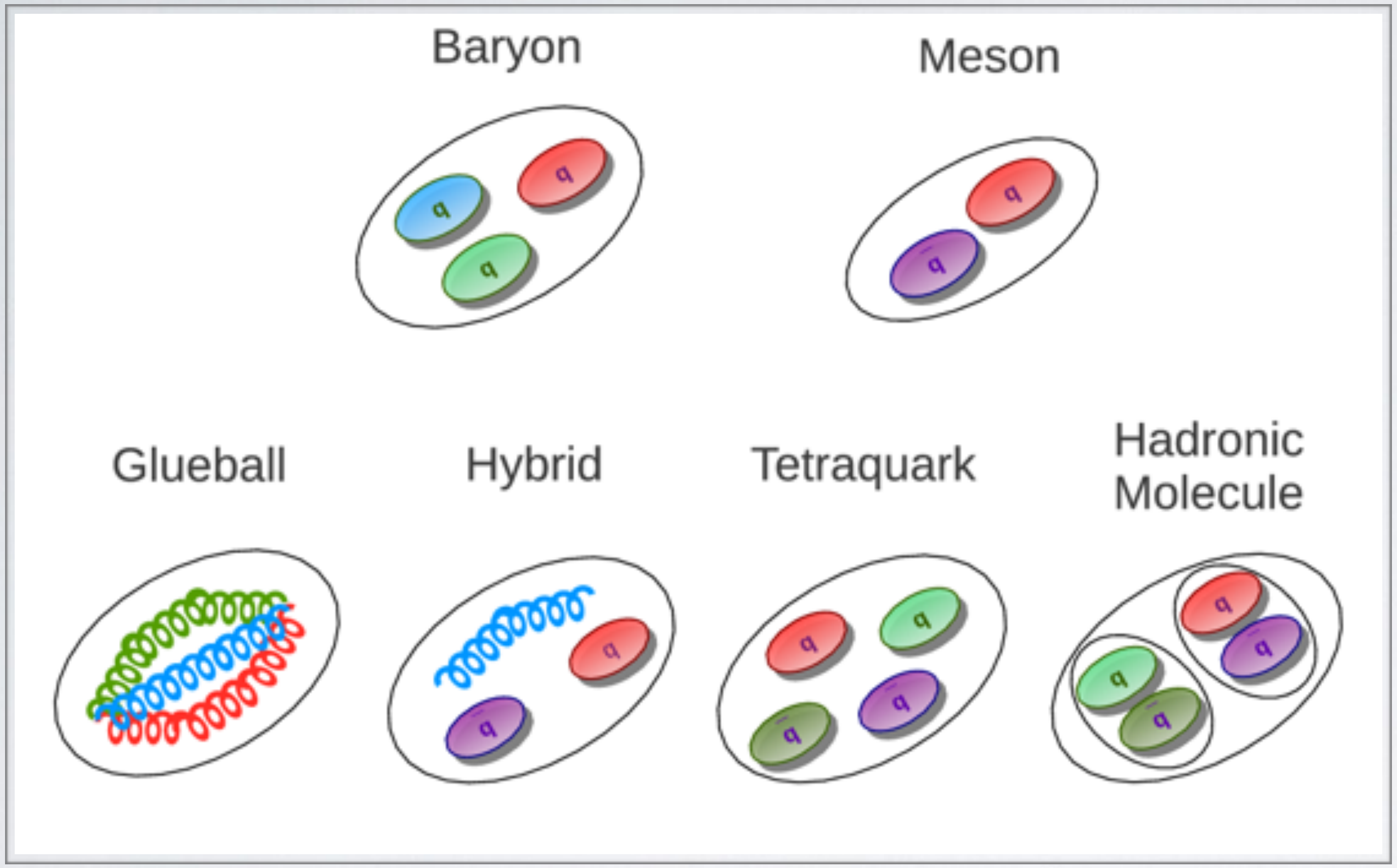
# JPAC activities

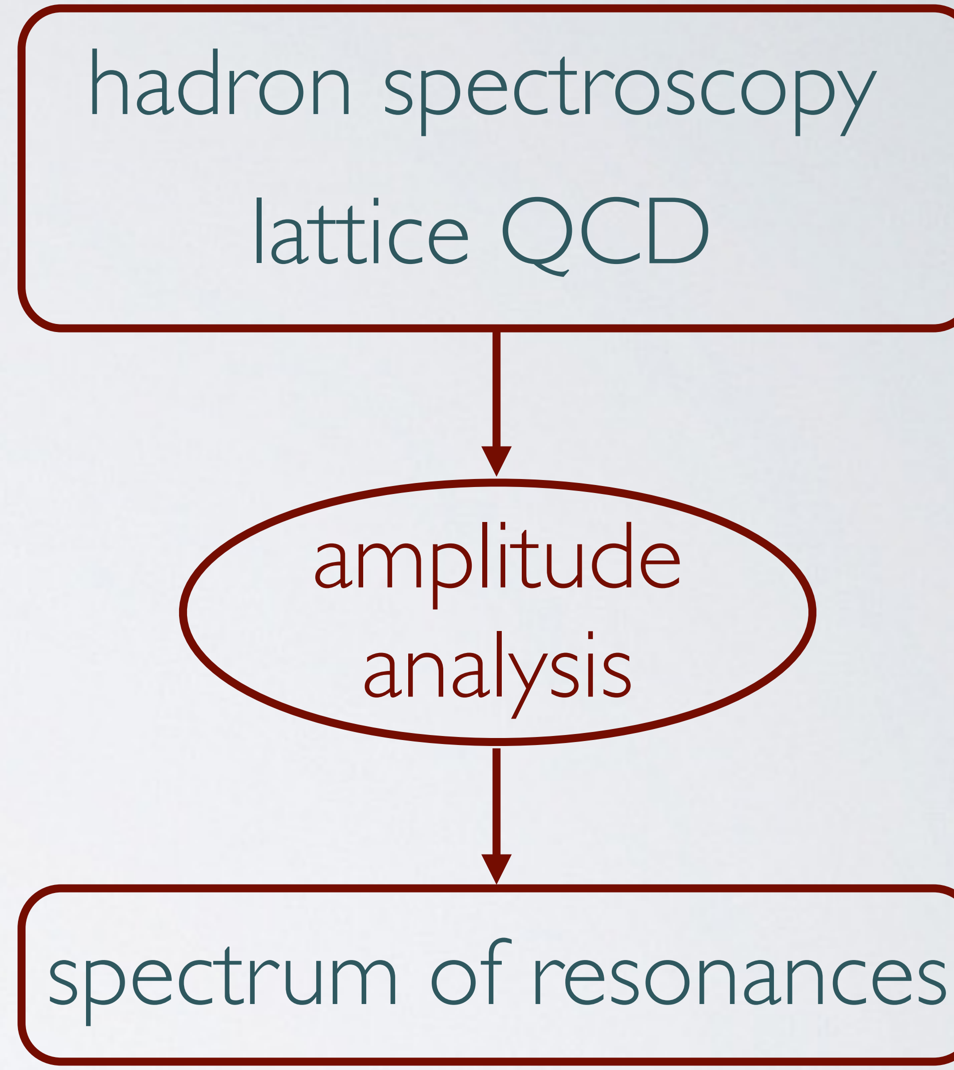
Vladyslav Pauk

CLAS collaboration meeting
JLab
February 25, 2016

# Hadron spectroscopy






- Extract values of fundamental parameters
- Extract properties of resonances
- Searches for new resonances/new states of matter
- Understand fundamental laws (matching QCD with exp.)

**JPAC**

# Amplitude analysis



**unitarity**

$$2\text{Im}\ T = iTT^\dagger$$

**analyticity**

$$A(s,t) = \frac{2}{\pi}\int_{s_{th}}^{\infty} \frac{\text{Im}(s',t)}{s'-s}\text{d}s'$$

**crossing symmetry**

s $1+2 \to 3+4$

t $1+\bar{3} \to \bar{2}+4$

u $1+\bar{4} \to 2+\bar{3}$

consistent fitting functions
constraints from existing data
Finite Energy Sum Rules (FESR)

**Lorentz symmetry, quantum numbers, etc.**

**model predictions**
**data**
**lattice simulations**

# Finite Energy Sum Rules



$$A(\nu,t)=\frac{2}{\pi}\int_{\nu_{th}}^{\infty}\frac{\mathrm{Im}A(\nu',t)}{\nu'^2-\nu^2}\nu\mathrm{d}\nu'$$

fixed-t dispersion relation

$$\nu=\frac{s-u}{2}$$

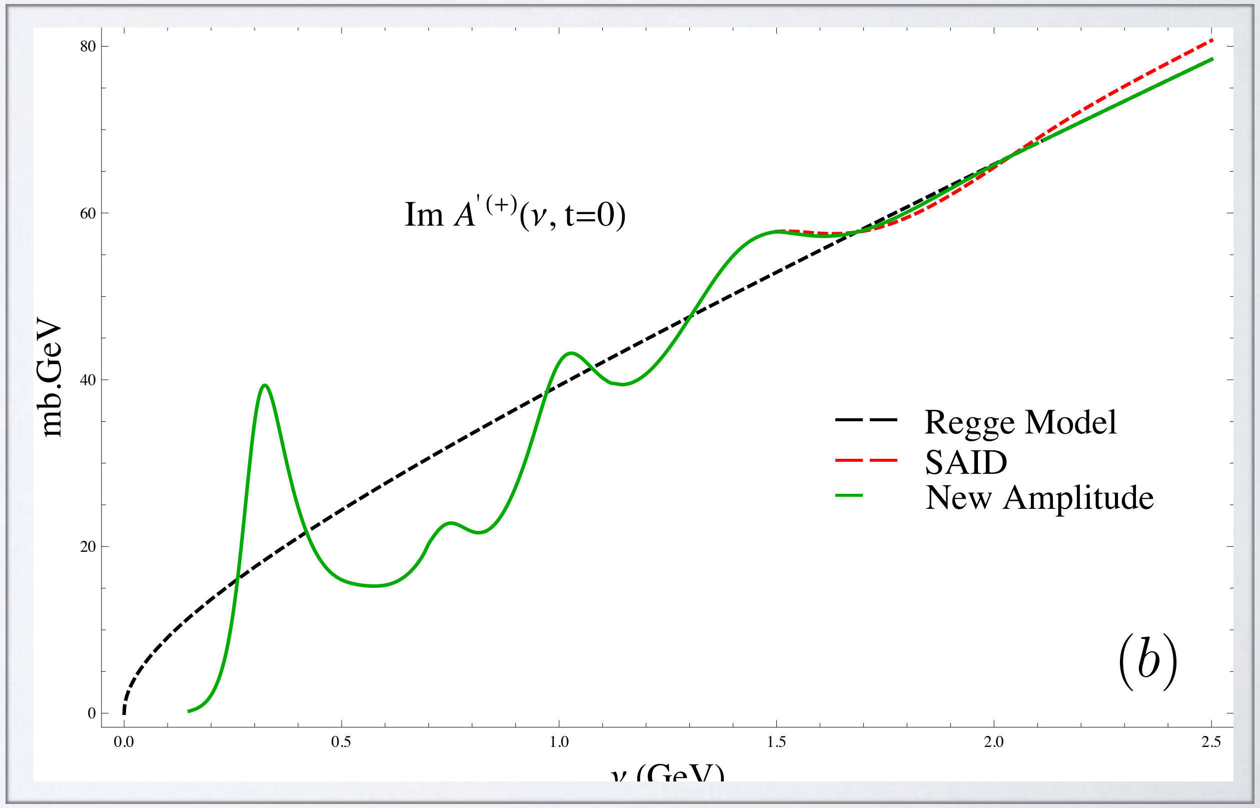
$$A(\nu,t)\to A(\nu,t)-A(\nu\to\infty,t)$$

$$A(\nu,t)\xrightarrow[\nu\to\infty]{}\beta(t)\nu^{\alpha(t)}$$

high-energy behavior

$$\frac{1}{\Lambda^n}\int_{\nu_{th}}^{\Lambda}\mathrm{Im}A(\nu,t)\nu^n\mathrm{d}\nu=\frac{\beta(t)\Lambda^{\alpha(t)+1}}{\alpha(t)+n+1}$$

**Finite Energy Sum Rules**

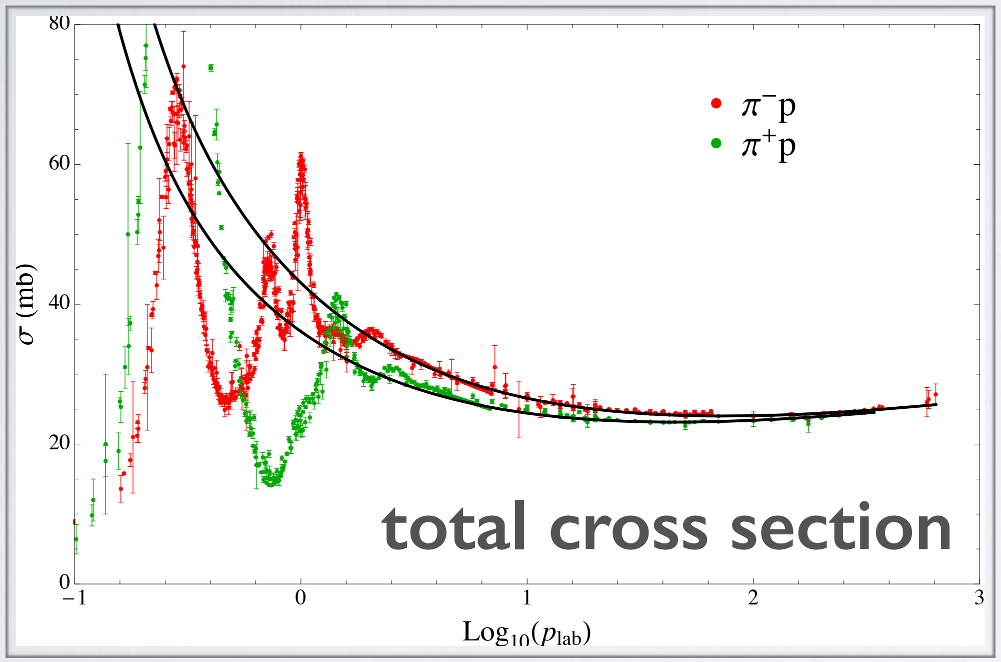


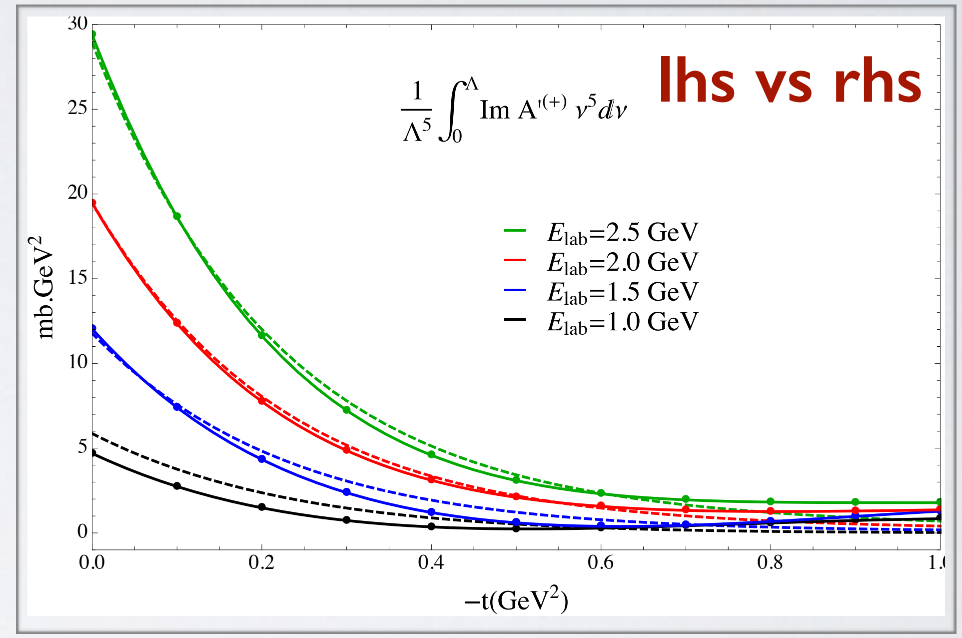
# Pion-Nucleon Amplitudes

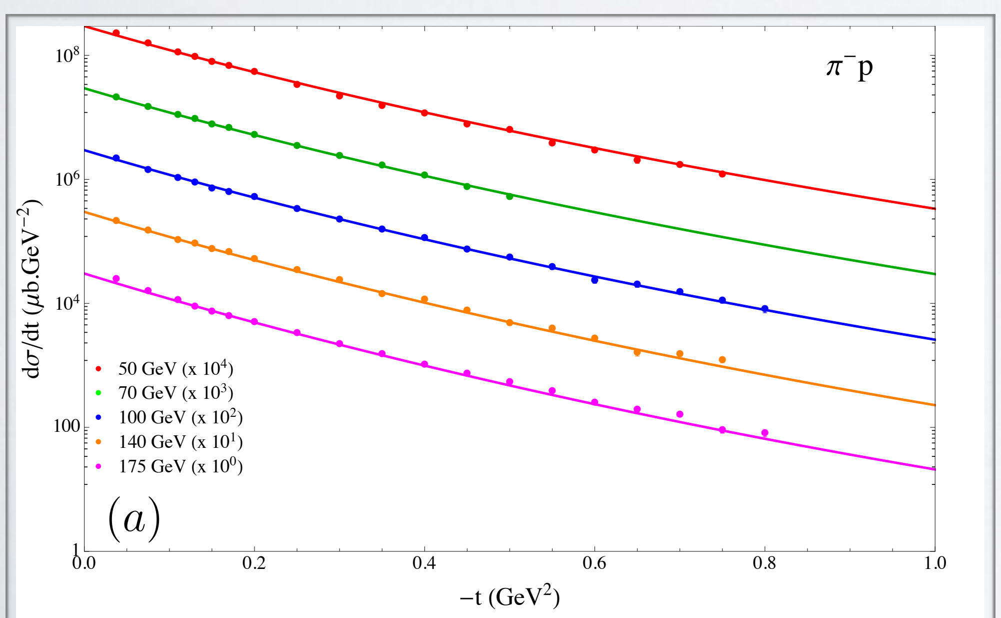


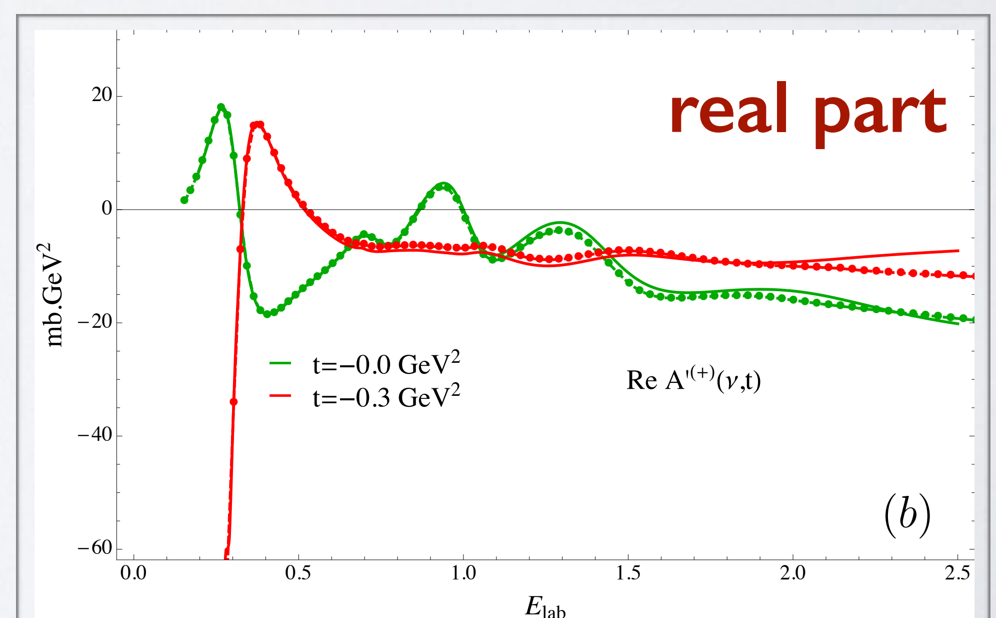
high-energy fit to total
and differential cross sections

$$\pi^{\pm} p \to \pi^{\pm} p \qquad \pi^{-} p \to \pi^{0} n$$



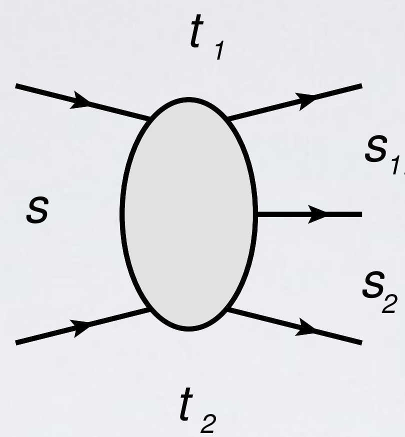




Mathieu, V., et al. PRD, 92(7), arXiv:1506.01764

# ηπ production at COMPASS

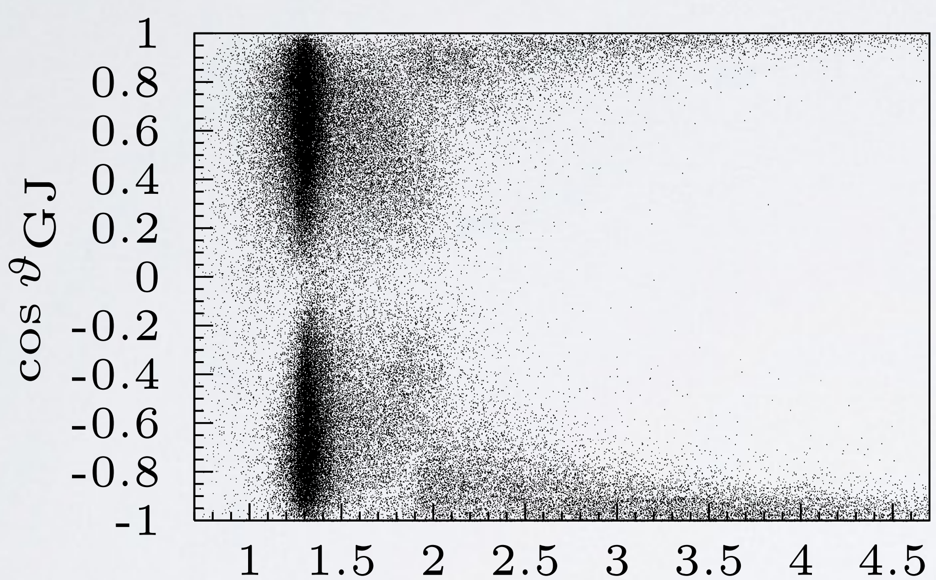
$$\pi^- p \rightarrow \eta \pi^- p$$

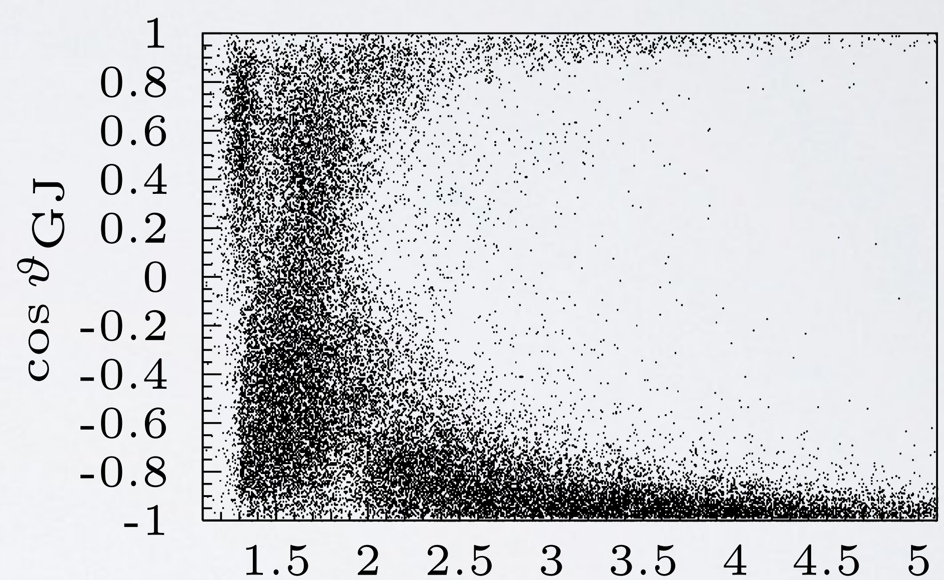
$$\pi^- p \rightarrow \eta' \pi^- p$$

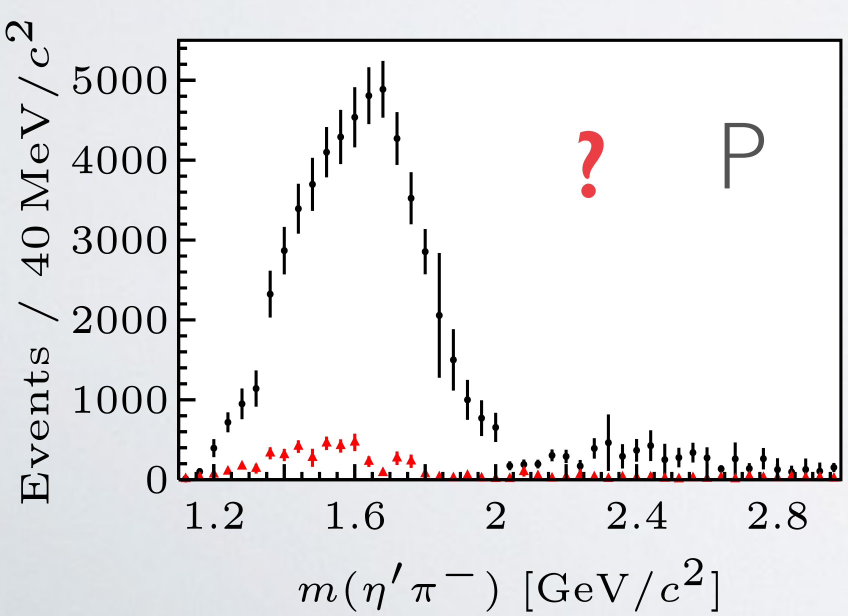


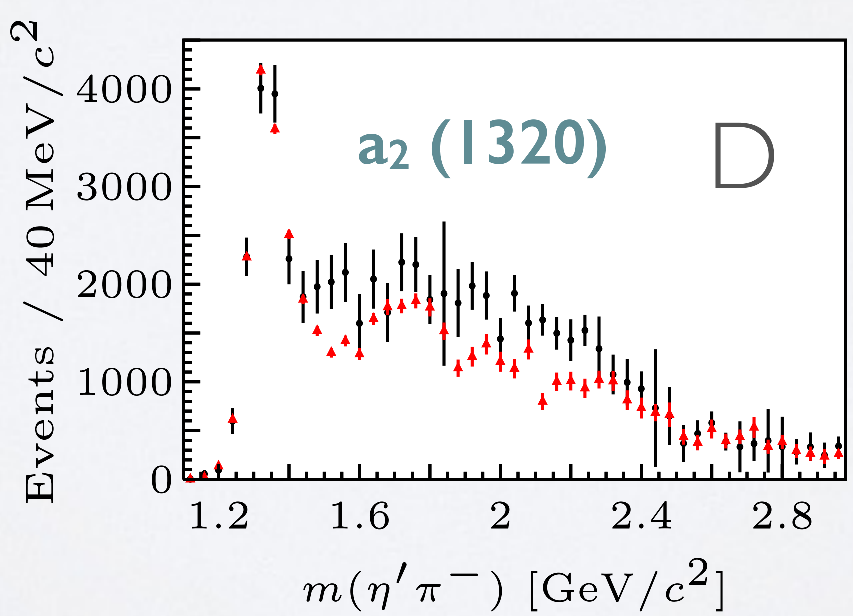

$$J^{PC} = 1^{-+}, 3^{-+}, 5^{-+}, \ldots$$

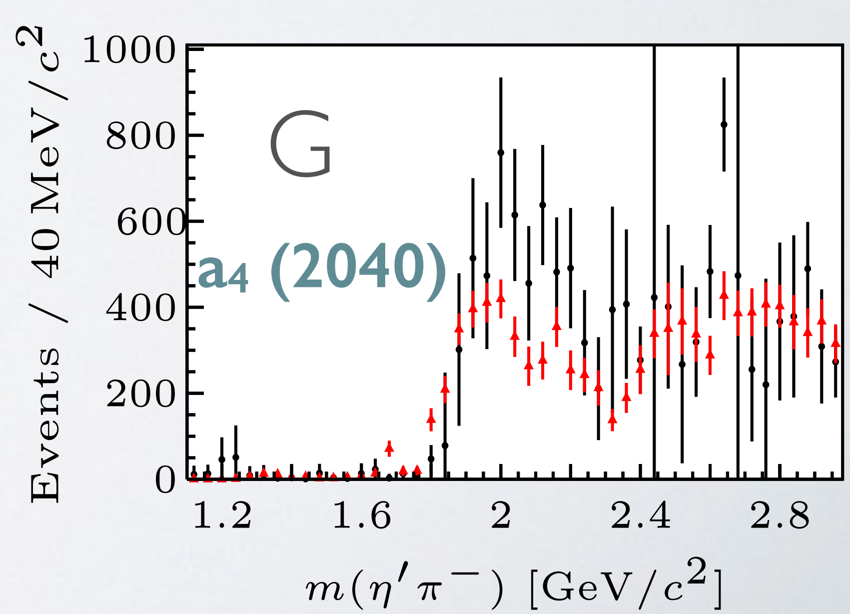
exotic quantum numbers



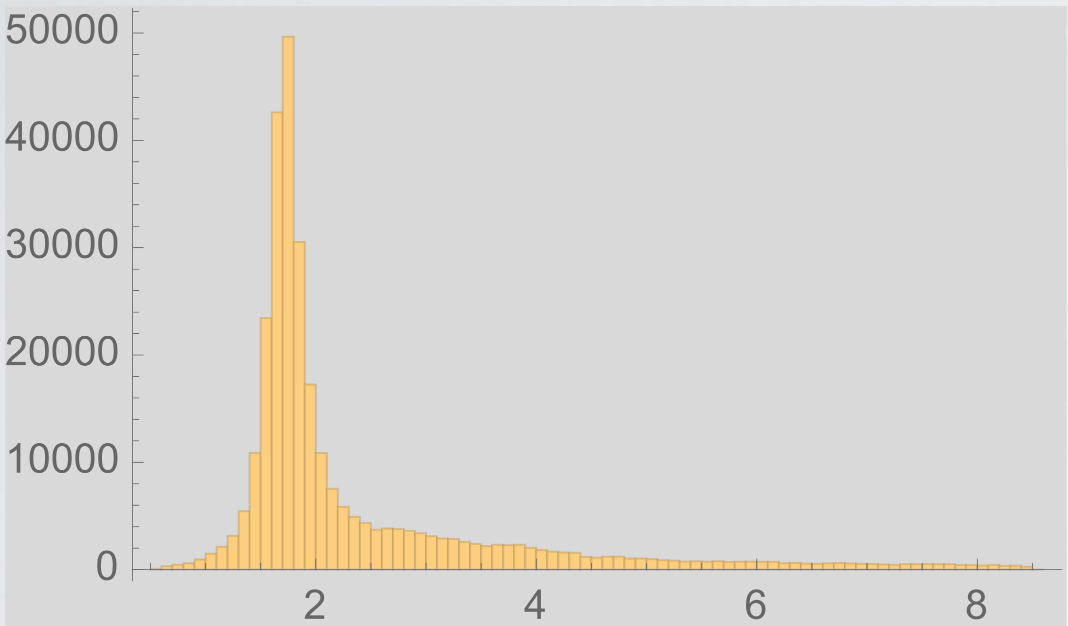



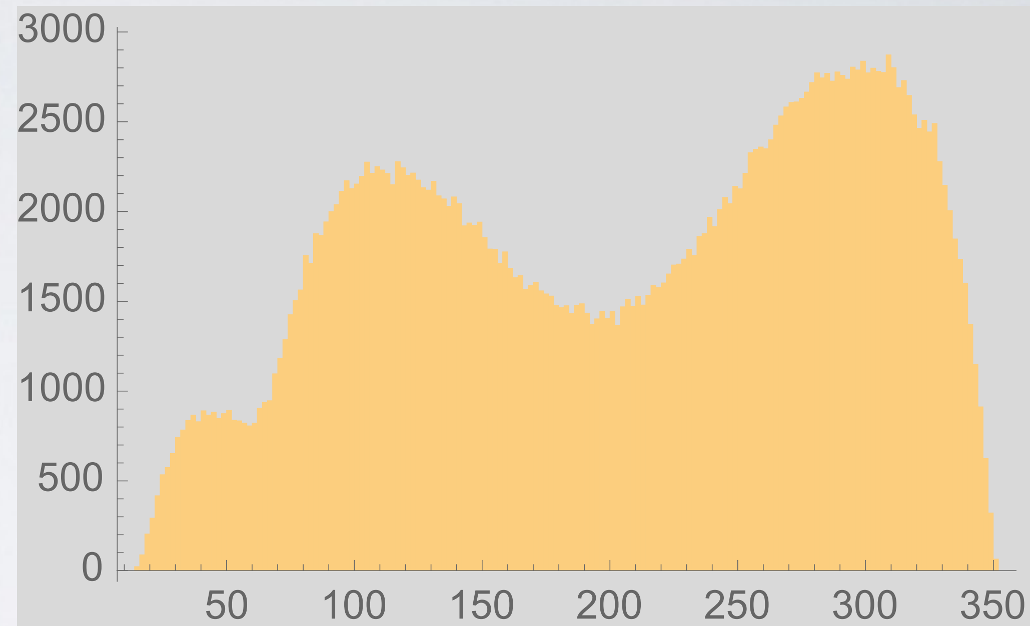
# Kinematic ranges



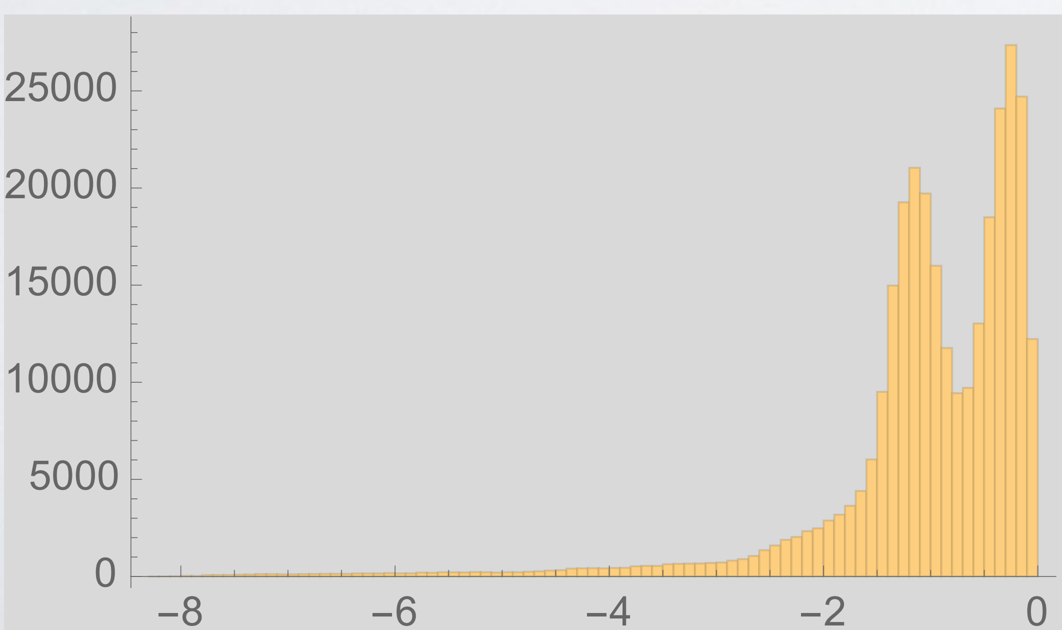
$$0.5 \text{ GeV} < s_1 = (p_1 + p_2)^2 < 5 - 6 \text{ GeV}$$



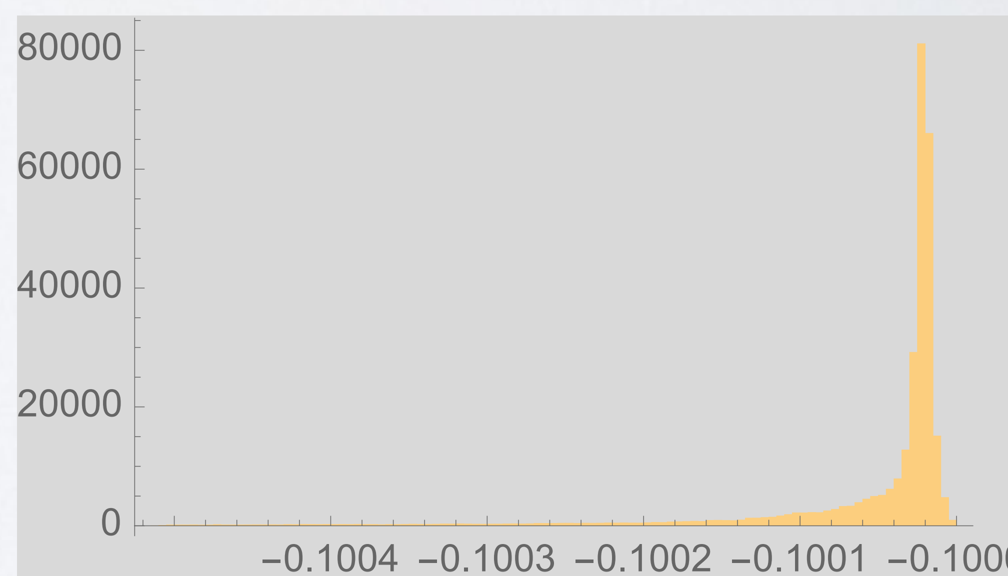

$$15 \text{ GeV} < s_2 = (p_2 + p_3)^2 < 350 \text{ GeV}$$




$$0 \text{ GeV} > t_1 = (p_a - p_1)^2 > -2 \text{ GeV}$$

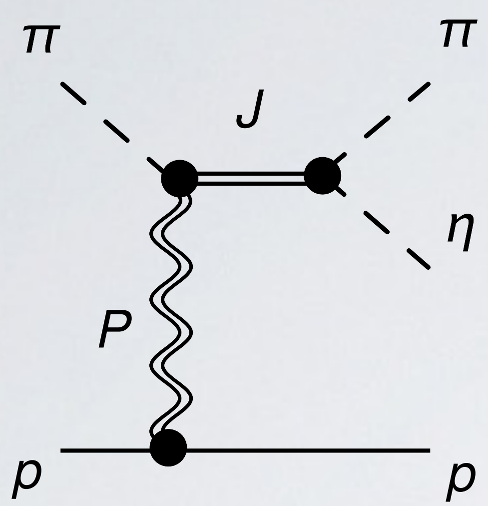



$$t_2 = (p_b - p_3)^2 \approx -0.1 \text{ GeV}$$



# Production mechanism






**resonance production**

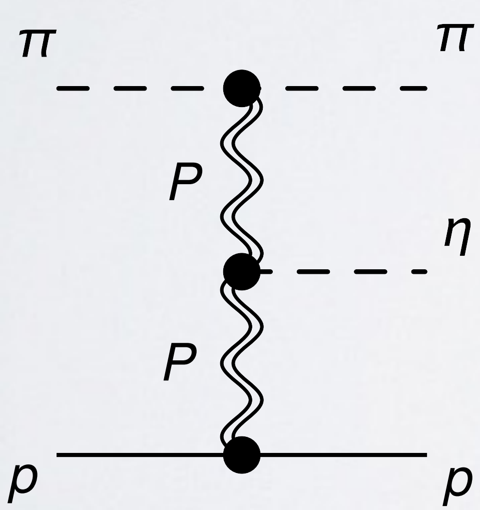
partial-wave expansion

$$A_{\mu\mu'}(s_1,s_2,t_1,t_2) = \boxed{\sum_{\lambda=-J}^{J} A^J_\lambda(s_1,t_2)\frac{g_J(s_1)}{m_J^2 - i m_J\Gamma(s_1) - s_1} d^J_{\lambda 0}(z) e^{i\lambda\phi}}$$

$$\times\, \eta(\alpha_2(t_2))\gamma_{2\mu\mu'}(t_2) s_2^{\alpha_2(t_2)}$$

Regge behavior

**FESR**




$$A_{\mu\mu'}(s_1,s_2,t_1,t_2) = \boxed{\eta(\alpha_1(t_1))\gamma_1(t_1) s_1^{\alpha_1(t_1)} \sum_\lambda e^{i\lambda\omega}\gamma_\lambda(t_1,t_2)}$$

$$\times\, \eta(\alpha_2(t_2))\gamma_2^{\mu\mu'}(t_2) s_2^{\alpha_2(t_2)}$$

**central production**

Toller angle

$$\cos\omega = \left.\frac{(\mathbf{p}_a\times\mathbf{p}_1)\cdot(\mathbf{p}_b\times\mathbf{p}_3)}{|\mathbf{p}_a\times\mathbf{p}_1||\mathbf{p}_b\times\mathbf{p}_3|}\right|_{\mathbf{p}_2=0}$$

# Kinematic constraints



$$A_{H_s}(s,t) = 16\pi \sum_{J=M}^{\infty} (2J+1) A_{HJ}(s) \mathcal{D}^{J*}_{\mu\mu'}(\phi_s, \theta_s, -\phi_s)$$

$$\zeta_{\mu\mu'}(z_s) = \left(\frac{1-z_s}{2}\right)^{\frac{1}{2}|\mu-\mu'|} \left(\frac{1+z_s}{2}\right)^{\frac{1}{2}|\mu+\mu'|}$$

+ crossing symmetry or threshold behavior

**low-t dependence**

$$\gamma^{\lambda_1\lambda_2}(t) \sim (-t)^{|\lambda_1-\lambda_2|/2}$$

$$\gamma^{\lambda_2}_{\lambda\lambda_2-\lambda} \sim (-t_1)^{|\lambda_1|/2}(-t_2)^{|\lambda_2|/2}$$

**general form of the double-Regge residue**

parity

$$\gamma^{\lambda_h}_{\lambda_1\lambda_2} = - \gamma^{-\lambda_h}_{-\lambda_1-\lambda_2}$$

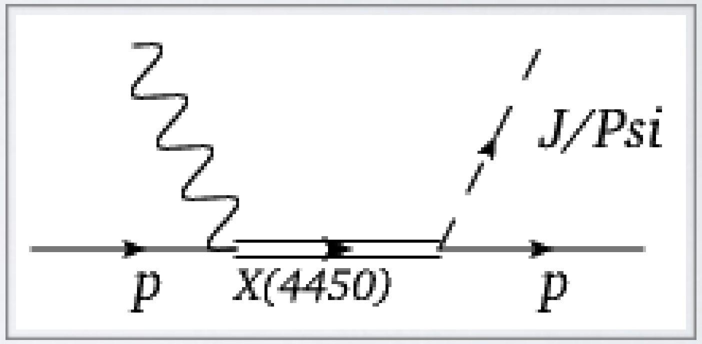
$$\gamma_0(t_1, t_2, \omega) = 0$$

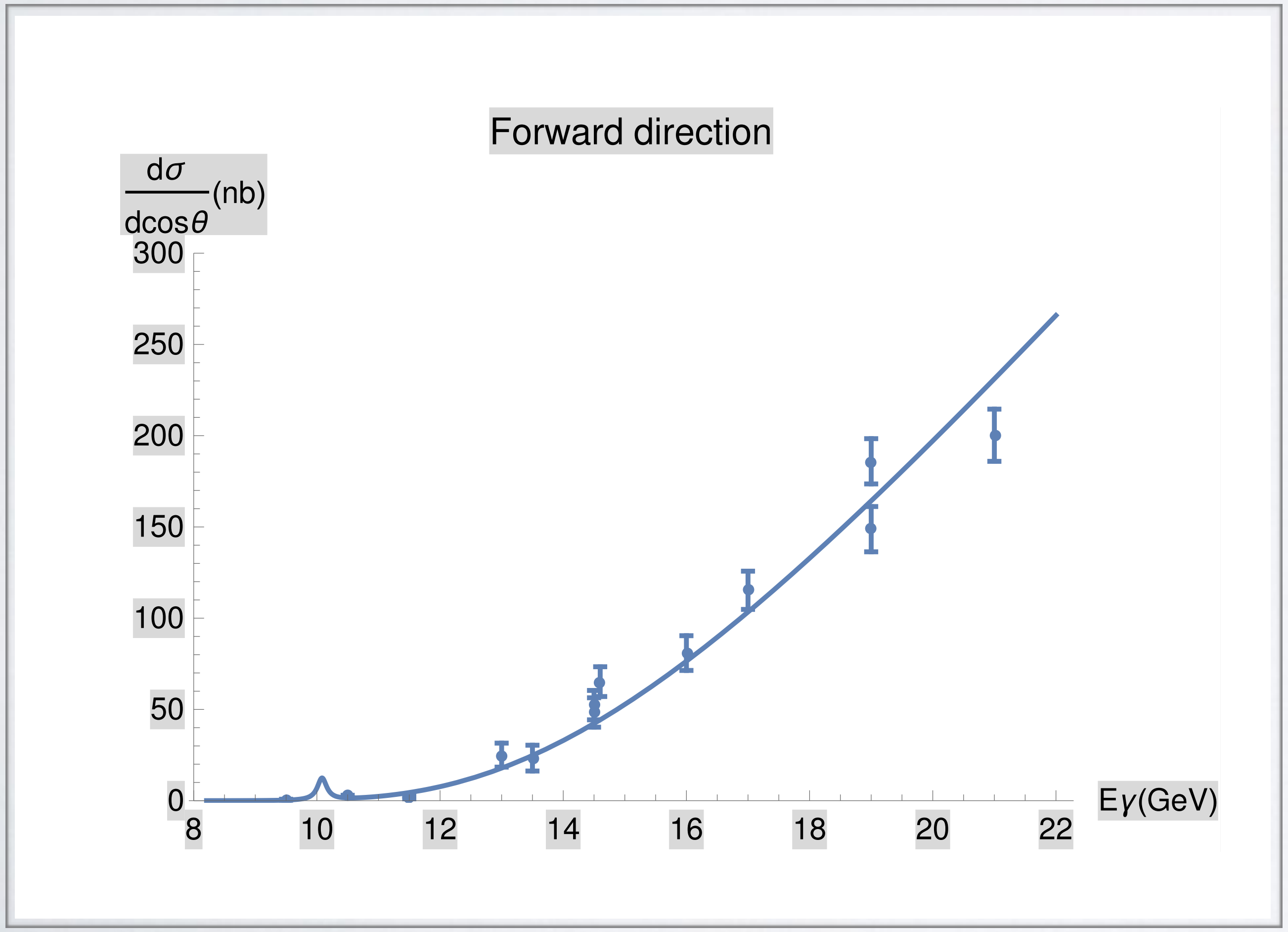
$$\beta(t_1, t_2, \omega) \sim 2i(-t_1)^{1/2}(-t_2)^{1/2} \sin\omega \sum_{\lambda=0}^{\infty} \sin^\lambda \omega \, \tilde{\gamma}_\lambda(t_1, t_2)$$

$$\beta(t_1, t_2, \omega) = \sum_{\lambda=-\infty}^{\infty} e^{i\lambda\omega} \gamma_\lambda(t_1, t_2)$$

# Studying the pentaquark in the J/Ψ photoproduction =9=

- Recent discovery of a narrow (39 MeV) exotic resonance compatible with a pentaquark $P_c(4459)$ in the J/Ψp channel.
LHCb collaboration (2015) arXiv:1507.03414
- Proposed as an excellent candidate for J/Ψ photoproduction off a proton target.
arXiv:1508.01496, arXiv:1508.00339, arXiv:1508.00888



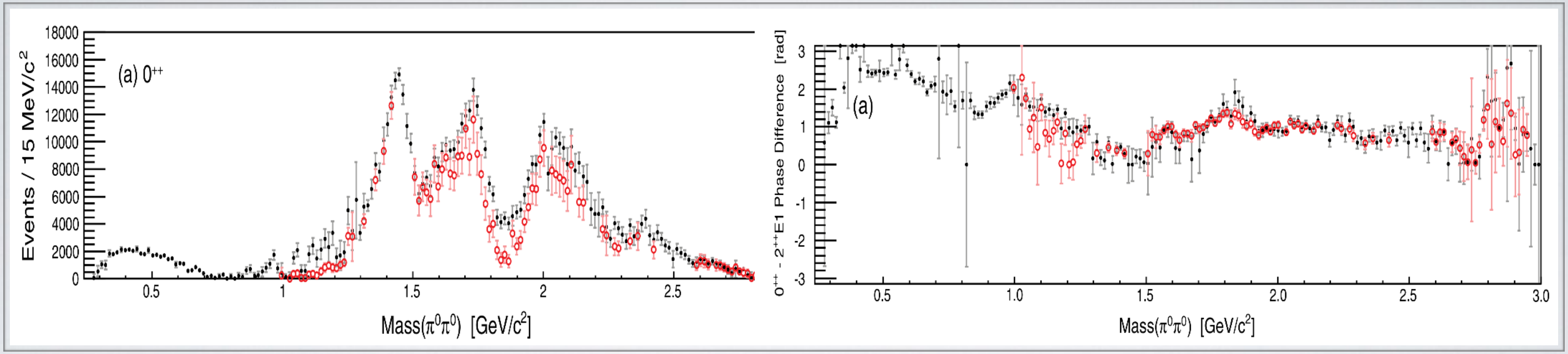

Testing these predictions is within the capabilities of **JLAB's CLAS** detector, also in a wider range of scattering angles!

A. Blin

# J/Ψ→γππ



Good channel for the search of ground-state scalar glueball
Data provided by BESIII both for the charged and neutral channel




$t$-channel dominated by $\rho$ exchange → model for LHC

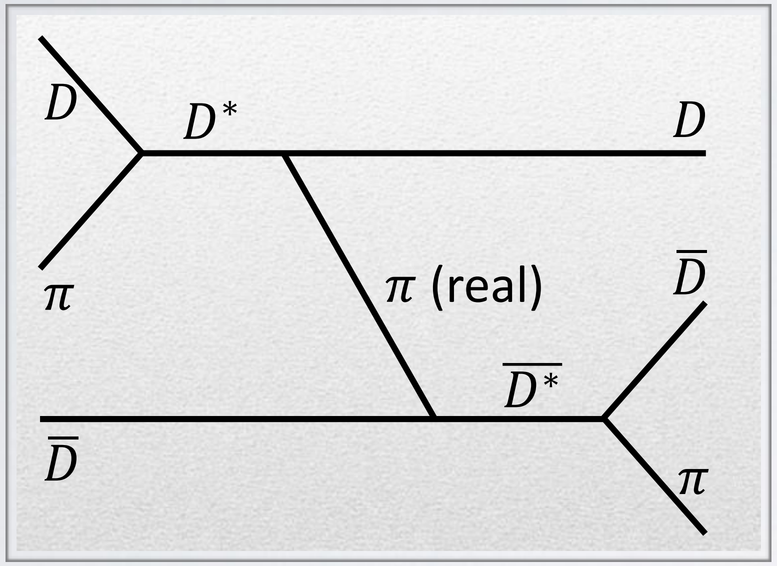
$$f_J(s) = \frac{1}{\pi}\int \frac{\text{disc} f_J^\rho(s')}{s'-s} + \frac{1}{\pi}\int_{4m_\pi^2}^{\infty} \frac{\eta \sin\delta_J e^{-i\delta_J} f_J(s')}{s'-s} \mathrm{d}s'$$

Solved in terms of the Omnès function up to $\sqrt{s} \sim 1.2\ \text{GeV}$
new parametrizations tested in the $1.2\ \text{GeV} < \sqrt{s} < M_\psi$

A. Pilloni

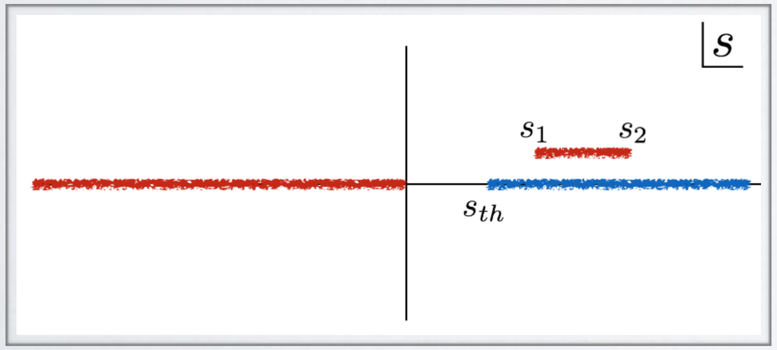
# 3-body scattering: $DD\pi \to DD\pi$ ( $X(3872)$ ) =11=

The dominant binding mechanism is expected to be the exchange of one pion in the u channel, but in the literature, this has been evaluated in the static limit only (virtual pion)




However, the $\pi$ can happen to be on shell: this creates another cut, which might spoil the binding mechanism of $DD^*$

Cusp effect if the branch points pinch the real axis

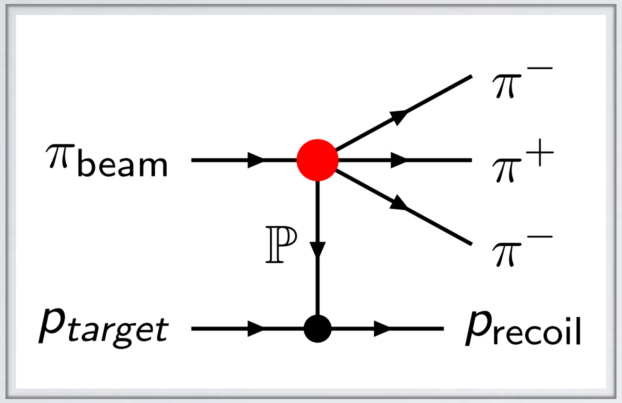


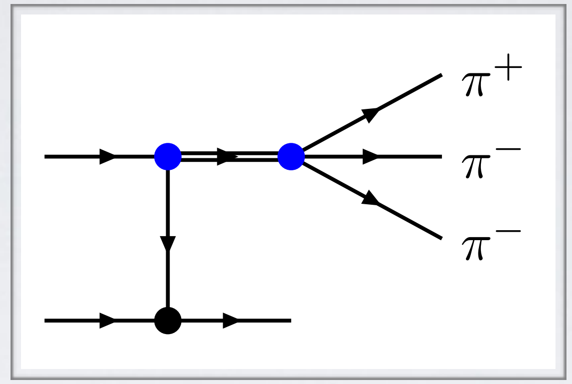

Once developed, the formalism can be extended to other 3 → 3 channels, like $\rho\,\pi \to \rho\,\pi$...

A. Pilloni

# $3\pi$ production at COMPASS experiment

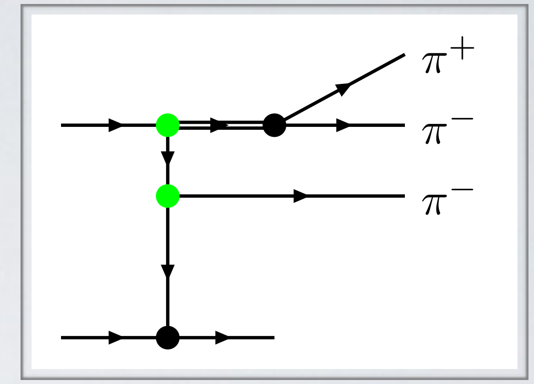





resonance production

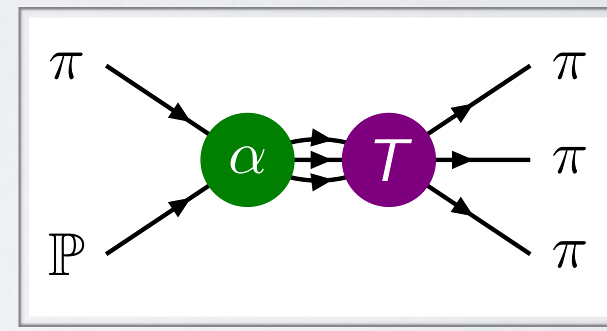
+




Deck-production amplitude

resonance production

$$A = \left\langle \pi\mathbb{P}|\hat{T}|3\pi \right\rangle =$$




- Unitarity has to be respected $\hat{S} \times \hat{S}^\dagger = \mathbb{I}$

$$2\mathrm{Im}T = iT\rho T^\dagger \qquad \hat{S} = \mathbb{I} + i\hat{T}$$

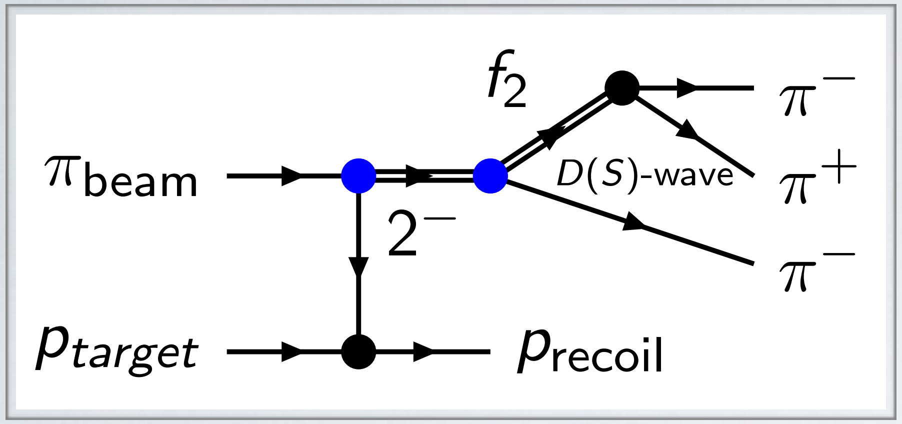
- Convenient parameterization of T is a K-matrix
- Non-resonance processes is a physical background?

$$2\mathrm{Im}A = iA\rho T^\dagger \qquad A(m_{3\pi}) = \alpha(m_{3\pi}) \times T(m_{3\pi})$$

- Quasi-two-body phase space ($f_2$ is $(\pi\pi)_D$-state)

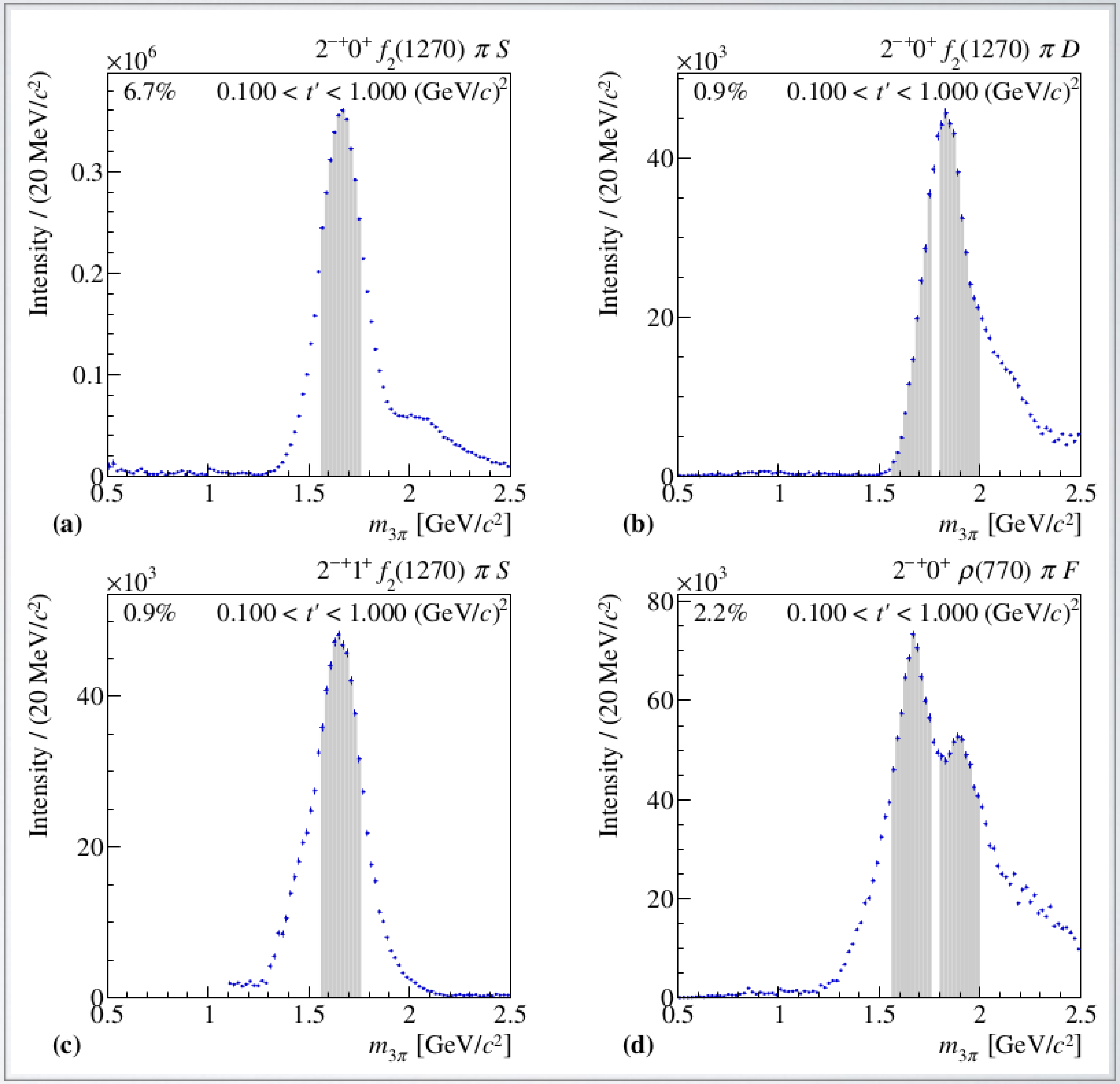
M. Mikhashenko, A. Jackura

# $2^{-+}$ sector of the $3\pi$ final state




Long standing puzzle about
$\pi_2(1670) - \pi_2(1880)$ interplay

The goal is to develop a method
of the analysis and
demonstrate an applicability.




M. Mikhashenko, A. Jackura

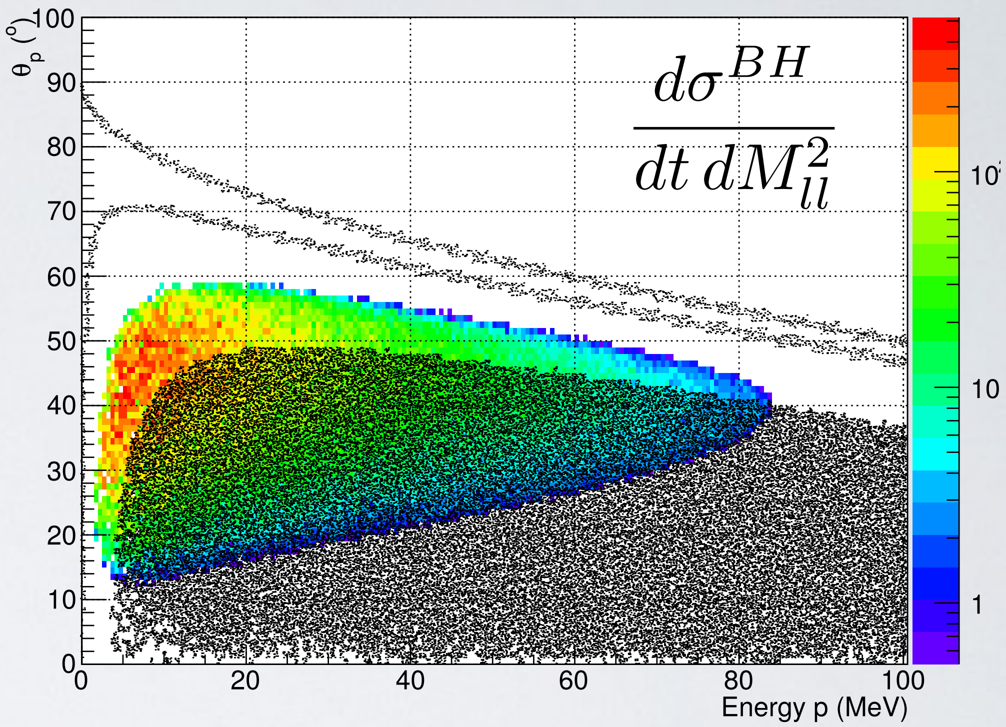
# Lepton pair production on a proton target



Measure the ratio of the e vs μ cross sections

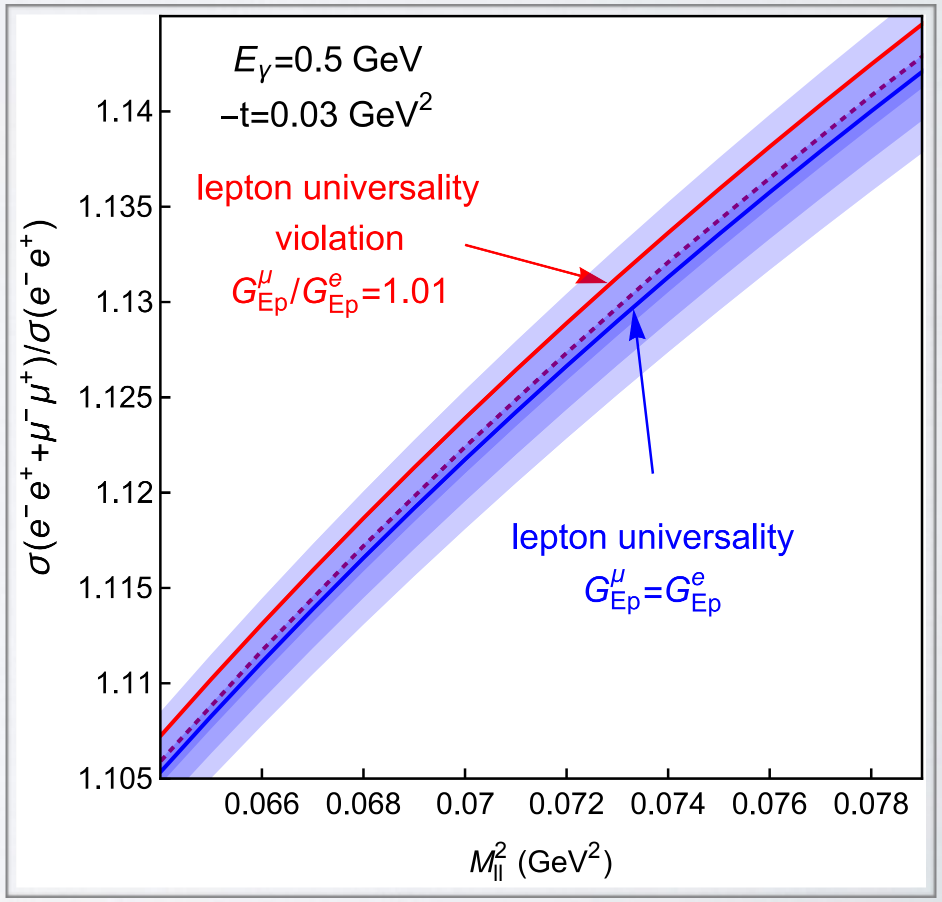
$$R_{\mu/e} \equiv \frac{d\sigma(\mu^-\mu^+ + e^-e^+)}{d\sigma(e^-e^+)} - 1$$

VP, Vanderhaeghen, Phys. Rev. Lett. 115, 221804




at small t the ratio $R_{\mu/e}$ gives **direct access** to the ratio of the **proton electric form factor** in the μp versus ep scattering

the deviation from the unity will be a sign of **violation of the lepton universality**




**JLab**

access the proton form factor by analyzing angular distributions of the lepton pairs

# Overview



| | | |
|---|---|---|
| $\pi N \to \pi N$ | V. Mathieu, et al. | arXiv:1506.01764<br>PRD92 7 074004 |
| $\gamma p \to \pi^0 p$ | V. Mathieu, et al. | arXiv:1505.02321<br>PRD92 7 074013 |
| $\eta \to \pi^+ \pi^- \pi^0$ | P. Guo, et al. | arXiv:1505.01715<br>PRD92 5 054016 |
| $\omega,\, \phi \to \pi^+ \pi^- \pi^0$ | I. Danilkin, et al. | arXiv:1409.7708<br>PRD91 9 094029 |
| $\gamma p \to K^+ K^- p$ | M. Shi, et al. | arXiv:1411.6237<br>PRD91 3 034007 |
| $KN \to KN$ | C. Fernandez-Ramirez, et al. | arXiv:1510.07065 |