2 PION QUASI-REAL PHOTOPRODUCTION ANALYSIS AT CLAS12

Marco Filippini

University of Messina & INFN Catania

Abstract

The study of hadron spectroscopy and nucleon resonance structure has entered a new precision era with the 12 GeV upgrade at Jefferson Lab. The CLAS12 detector, a large-acceptance spectrometer in Hall B, provides efficient charged and neutral particle detection over a wide solid angle.

We present a preliminary analysis of the exclusive quasi-real 2 pion photoproduction, from the reaction $ep \to ep\pi^+\pi^-$ where the virtuality of the exchanged photon $Q^2 \to 0$. This is needed to understand the mechanisms responsible for production of meson resonances decaying into two pions. The goal of the analysis is the extraction of the differential cross sections and moments of the $\gamma p \to \pi^+\pi^- p$ reaction. Selecting the properly kinematic range of the two-pion invariant mass and momentum transfer reveals some resonances like the ρ(770) and the $f_2(1270)$.

Quasi-Real Photoproduction

Photoproduction is the process where a photon interacts with a target hadron (like a proton or nucleus), typically producing new hadrons. The critical parameter is the photon's virtuality, which measures how far the photon is from being a real, massless particle.

A real photon (Q^2=0) has only transverse polarizations.

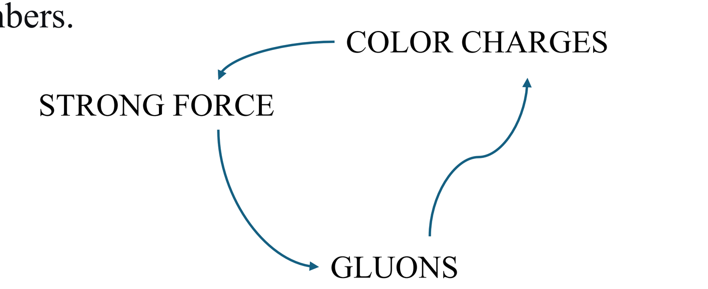
The quasi-real regime is defined by $Q^2 \approx 0$ but not exactly zero. This situation arises naturally when a fast charged particle (e.g., an electron or proton) emits a photon with very low transverse momentum. The photon is *almost* on-shell.

Meson Spectroscopy

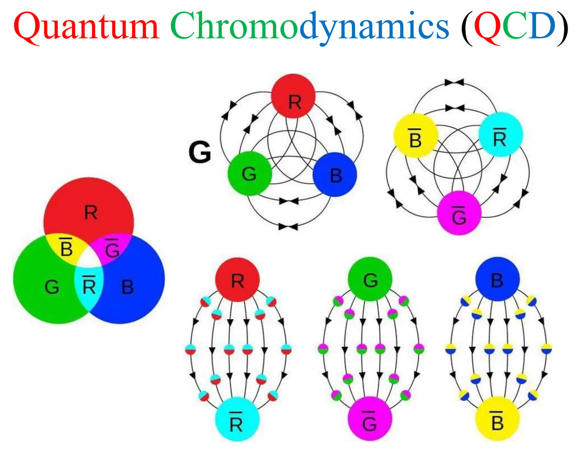
Quantum Chromodynamics (QCD) describes the strong interaction, where quarks and gluons are confined into color-neutral hadrons.

Hadron spectroscopy studies the excitation spectra of these hadrons, providing a critical test of QCD in the non-perturbative regime.

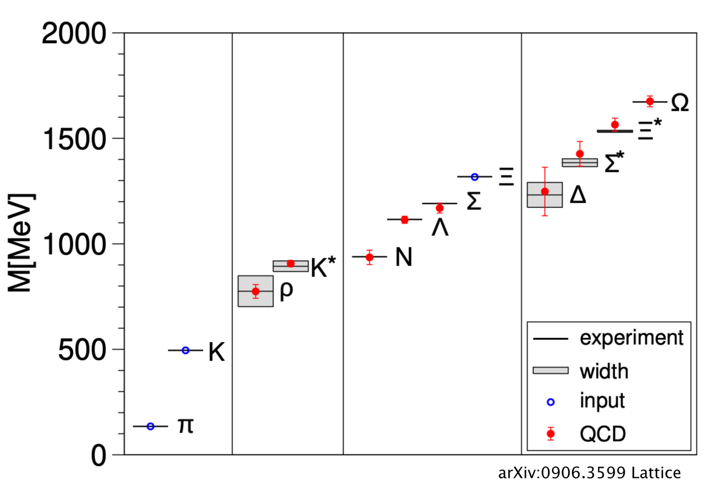
By measuring production cross sections and decay angular distributions, we can identify resonant states and their quantum numbers.



Quantum Chromodynamics (QCD)



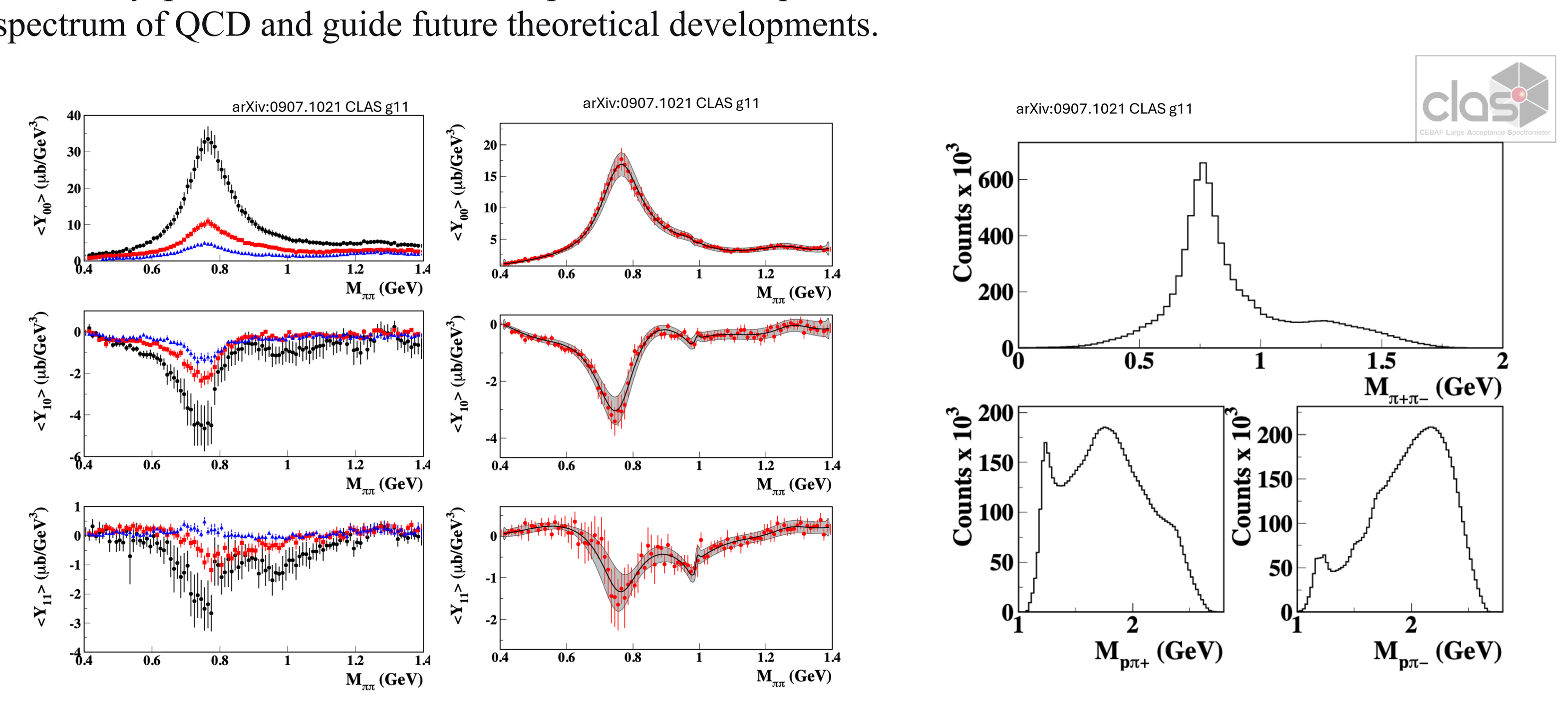
Hadrons are observed as resonances in scattering experiments.



Meson spectroscopy provides a direct window into the non-perturbative regime of QCD, where quarks and gluons are confined into hadrons.

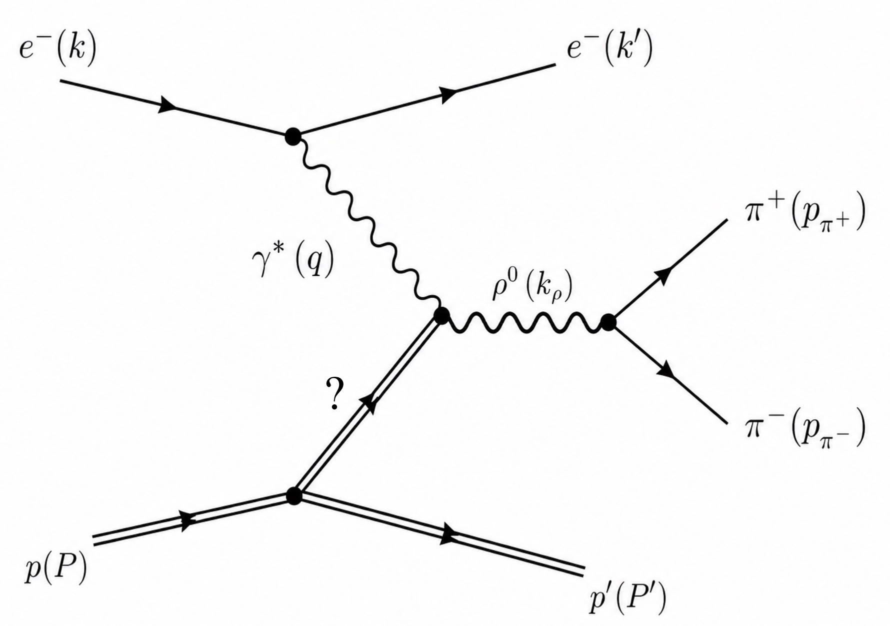
These measurements also help to identify excited states, radial excitations, and potentially exotic mesons (hybrids, glueballs) that lie beyond the simple quark-antiquark picture.

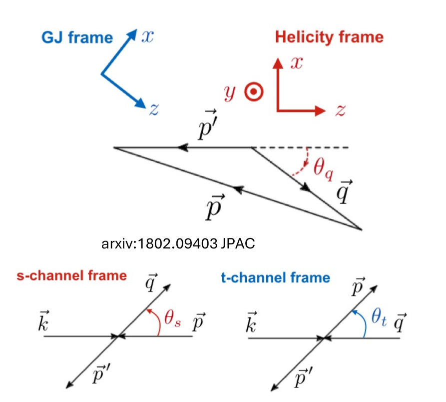
Ultimately, precise cross sections and partial wave amplitudes from CLAS12 data will constrain the spectrum of QCD and guide future theoretical developments.

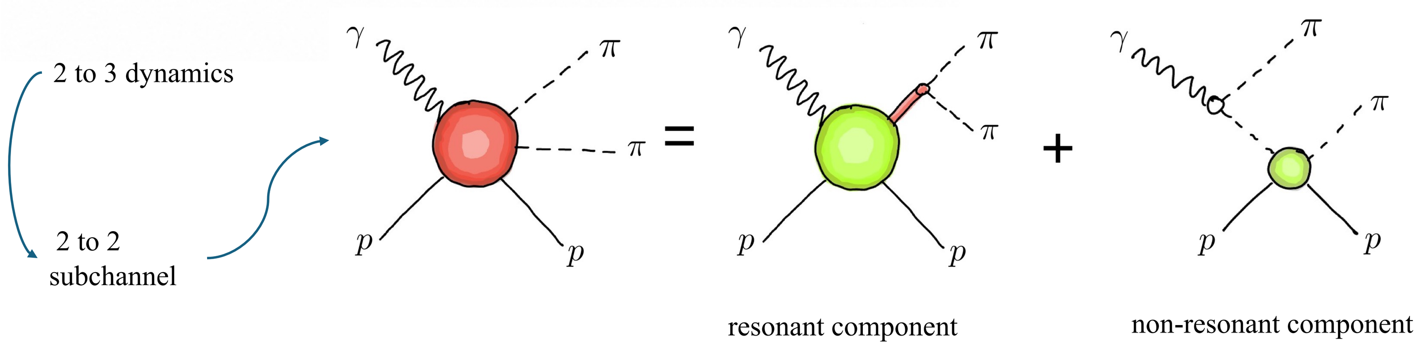


Analysis of channel $\gamma^* p \to p\,\pi^+\pi^-$

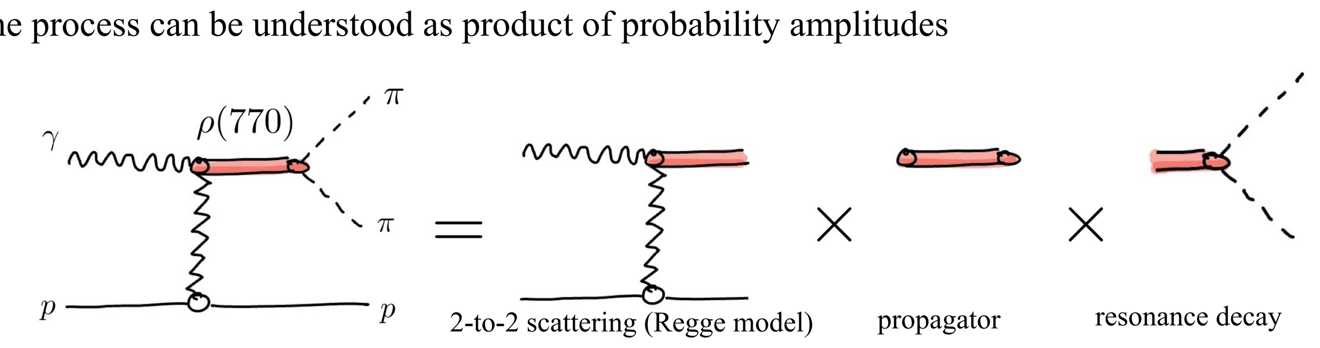
- S-wave (L=0) → $f_0(500)$, $f_0(980)$
- P-wave (L=1) → $\rho^0(770)$
- D-wave (L=2) → $f_2(1270)$



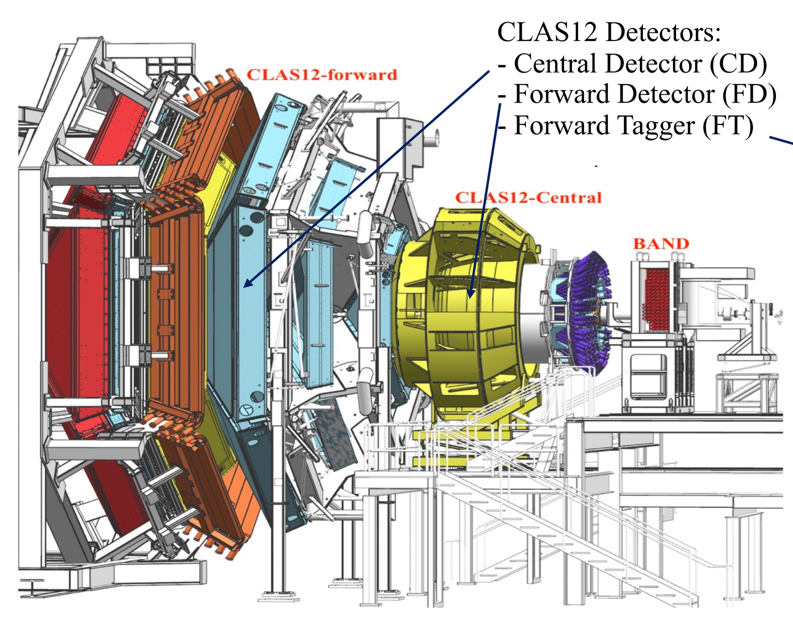




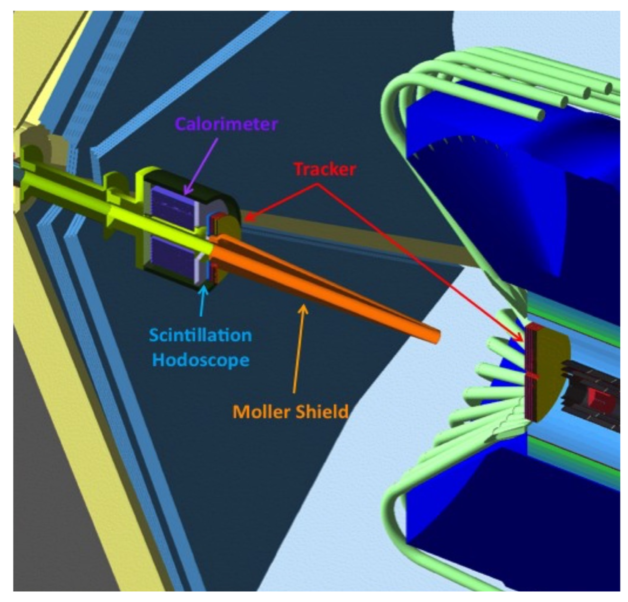
The process can be understood as product of probability amplitudes



The CLAS12 Experiment



CLAS12 Detectors:
- Central Detector (CD)
- Forward Detector (FD)
- Forward Tagger (FT)



CLAS12 Magnets:
- Torus (0.5-10 GeV)
- Solenoid(0.3-1.5 GeV)

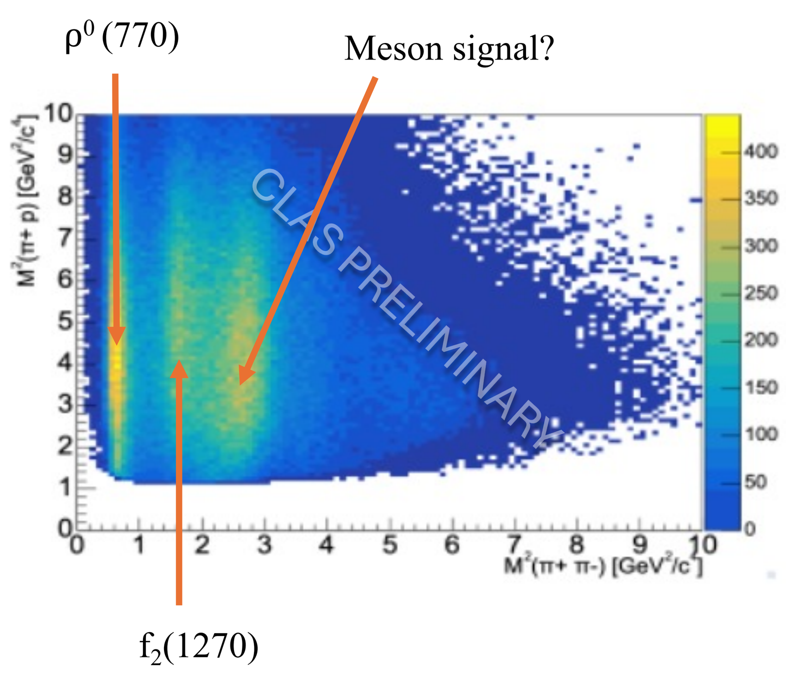
Parameter	Value
Charged tracks:	
Polar angular range (θ)	8° to 140°
Polar angular resolution ($\delta\theta$)	$\simeq$ 1 mr
Azimuthal angular resolution ($\delta\phi$)	$\simeq$ 4 mr
Momentum resolution ($\delta p/p$)	$\simeq$ 1%
Neutral particles:	
Polar angular range (θ)	8° to 45°
Energy/momentum resolution	$\simeq 0.1/\sqrt{(E)}$
Particle identification:	
π/p	< 3.5 GeV/c
K/π	< 2.0 GeV/c

	Range	*Resolution*
$E_{e'}$	0.5 - 4.5 GeV	$2\%/\sqrt{E_{e'}(GeV)} \oplus 1\%$
$\theta_{e'}$	2.5^o - 4.5^o	1.7 %
$\phi_{e'}$	0° - 360°	2.8°
E_γ	6.5 - 10.5 GeV	0.9 - 0.14 %
Q^2	0.01 - 0.3 GeV^2 ($<Q^2> \simeq 0.1 GeV^2$)	

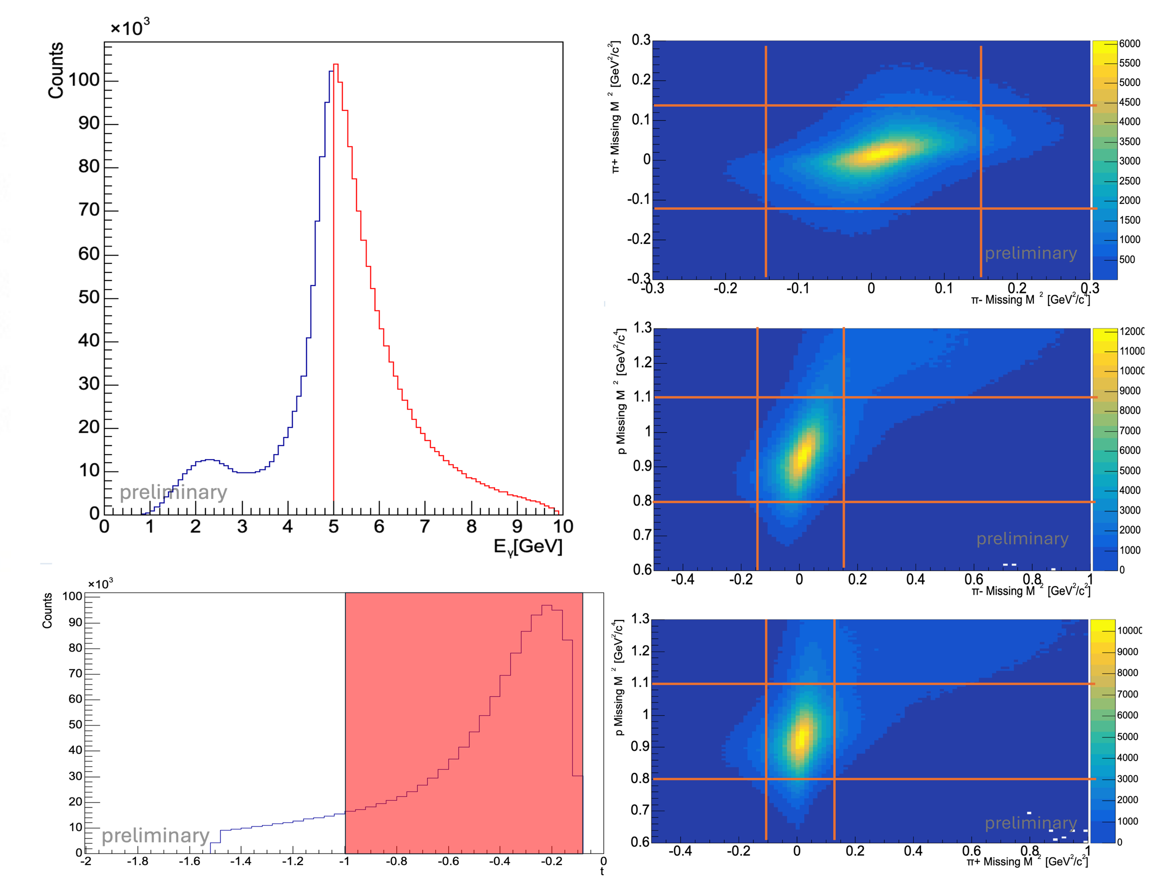
Same physics of quasi-real photoproduction

The Analysis Goal

The anaysis consists of looking for known meson resonances and extracting their production cross section.



Data selection



Focus on the resonances $\rho^0(770)$ and $f_2(1270)$.

The best way is extracting a set of observables called "moments", that allows to enhance the spin of individual resonances.

$$A(\Omega) = SY_0^0 + PY_m^1 + DY_m^2 + FY_m^3 + \dots$$

$$\frac{d\sigma}{d\Omega} = |A(\Omega)|^2$$

$$\int d\Omega \frac{d\sigma}{d\Omega} \simeq |S|^2 + |P|^2 + |D|^2 + \cdots \rightarrow \text{H\_0\_0\_0}$$

$$\int d\Omega \frac{d\sigma}{d\Omega} Y_0^1(\Omega) \simeq \mathrm{Re}\left(SP^* + |P|^2 + PD^* + DF^* + \cdots\right) \rightarrow \text{H\_0\_1\_0}$$

$$\int d\Omega \frac{d\sigma}{d\Omega} Y_0^3(\Omega) \simeq \mathrm{Re}\left(SF^* + PD^* + PF^* + DF^* + \cdots\right) \rightarrow \text{H\_0\_3\_0}$$

ignoring helicities, isospin, etc. etc.

$$\frac{dN}{d\Omega} = \sum_{LM} H^0_{LM}(m_{\pi^+\pi^-}, t) d^L_{M0}(\theta) \cos M\phi \times \alpha(m_{\pi^+\pi^-}, t, \theta, \phi)$$

Outlook

Moments of the $\pi^+\pi^-$ angular distribution have been successfully extracted in the invariant mass range $0.6<m_{\pi\pi}<1.85$ GeV/c^2.

The observed non-zero values of the second-order moments (Y_{20}) and ($Y_{2\pm2}$) clearly indicate the presence of D-wave (spin-2) contributions, consistent with the $f_2(1270)$ resonance, in addition to the dominant P-wave from the ρ(770).

Apply acceptance corrections to the extracted moments. This is currently in progress and will allow us to evaluate differential cross sections .

Perform a full Partial Wave Analysis (PWA) using the acceptance-corrected moments to disentangle the contributing waves (S, P, D, and possibly F) and extract resonance parameters (mass, width, helicity amplitudes) for ρ(770) and $f_2(1270)$.

Investigate the unexplored region above $m_{\pi\pi}>1.85$ GeV/c^2, where the data also show significant population.

Study systematic uncertainties in the moment extraction and acceptance correction (event selection, background subtraction, binning), which will be essential for the final cross section and PWA.

References

S. Durr *et al.* (BMW) "*Ab-initio Determination of Light Hadron Masses*", Science, 322, 1224-1227, arXiv:0906.3599.

M. Battaglieri, R. De Vita, A. P. Szczepaniak, *et al.* (CLAS). "*Photoproduction of π+π− meson pairs on the proton*". Phys.Rev. D, 80, 072005, arXiv:0907.1021.

R. Wishart. *Analysis of three body decays in quasi-real photoproduction* (Doctoral thesis, University of Glasgow 2023).

A. Celentano. *The Forward Tagger detector for CLAS12 at Jefferson Laboratory and the MesonEx experiment* (Doctoral thesis, University of Genova 2014).

D. I. Glazier, and V. Mathieu. "*Elliptical Polarization in Partial Wave Analysis of Two Spinless Meson Photoproduction*". Phys.Rev. D, 112, 116015, arXiv:2509.18827.

M. Battaglieri, R. De Vita, A. P. Szczepaniak, *et al.* (CLAS). "*Photoproduction of π+π− meson pairs on the proton*". Phys.Rev D, 80, 072005, arXiv:0907.1021.

V. Mathieu, *et al.* (JPAC). "*Vector Meson Photoproduction with a Linearly Polarized Beam*". Phys.Rev D ,97, 094003, arXiv:1802.09403.

Contacts

mafilippini@unime.it