Meson spectroscopy at CLAS and CLAS₁₂: the present and the future

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Why hadron spectroscopy?

- QCD is responsible for most of the visible mass in the universe
- Precise determination of the spectrum and properties of hadrons is necessary to reach a deep understanding of QCD
 - Revealing the nature of the mass of the hadrons
 - Identify the relevant degrees of freedom
 - Understand the origin of confinement
 - ...
- Meson spectroscopy is a key tool to investigate these issues

$\ll 0.1 \text{ fm}$

Quarks and Gluons

$0.1 - 1 \text{ fm}$

Effective Degrees of Freedom

$> 1 \text{ fm}$

Mesons & Baryons

Meson Spectroscopy

Objective:

Mesons are the simplest quark bound state, i.e. the best benchmark to understand how quarks interact to form hadrons and what the role of gluons is

- precise determination of the meson spectrum
- search for unusual states as hybrids (q $\bar{q}g$), tetraquarks (qq $\bar{q}\bar{q}$) and glueballs

Technique:

Use tagged photon beams to produce the mesonic state and isolate the single states by detecting the decay products

- Use of $S=1$ probe provides complementary information to $S=0$ (pion beams) probes
- Measurement of the decay products and PWA to isolate single resonances
- Full determination of initial state allows to study the production mechanism
- **High intensity photon beams and large acceptance detector are needed!!**

Hybrids and Exotics

A possibility to identify unambiguously a meson as an hybrid state is to look for *exotic quantum numbers*

- * Normal mesons ($q\bar{q}$) are classified according to their J^{PC} where

$$P = (-1)^{L+1}$$

$$C = (-1)^{L+S}$$

$$J^{PC} = 0^{-+} \Rightarrow (\pi, K, \eta, \eta')$$

$$1^{--} \Rightarrow (\rho, K^*, \omega, \Phi)$$

$$1^{+-} \Rightarrow (b_1, K_1, h_1, h_1')$$

$$\dots$$

- * Some combinations of J^{PC} are not allowed for conventional $q\bar{q}$ systems but can exist for “unconventional” states as hybrids

Normal meson:

flux tube in ground state
 $m=0$, $PC=(-1)^{S+1}$

Hybrid meson:

flux tube in excited state
 $m=1$, $PC=(-1)^S$

- * Excitation of the flux tube leads to a **new spectrum of hadrons** that can have **exotic quantum numbers** $J^{PC} = 0^{+-}, 1^{-+}, 2^{+-} \dots$
- * Lattice QCD calculations predict masses around 2 GeV, a range that can be explored at Jefferson Lab

Search for Exotics in Photoproduction

- * Photoproduction: exotic J^{PC} are more likely produced by $S=1$ probe

Pion Beam

Quark spins
anti-aligned
 $J^{PC} = 1^{--}, 1^{++}$

Photon Beam

Quark spins
already aligned
 $J^{PC} = 0^{+-}, 1^{-+}, 2^{+-}$

- * Production rate for exotics is expected to be comparable to regular mesons

Few data (so far) but
expected similar production
rate as regular mesons

A. Szczepaniak and M. Swat, Phys. Lett. B516 (2001) 72

Jefferson Lab

Continuous Electron Beam Accelerator Facility

- $E: 0.75 - 6 \text{ GeV}$
- $I_{\text{max}}: 200 \mu\text{A}$
- $\text{RF}: 1499 \text{ MHz}$
- $\text{Duty Cycle}: \sim 100\%$
- $\sigma(E)/E: 2.5 \times 10^{-5}$
- $\text{Polarization}: 80\%$
- Simultaneous distribution to 3 experimental Halls

The CLAS detector at JLab

CEBAF Large Acceptance Spectrometer

Hall-B Photon Tagger

- Photon beam produced from the primary electron beam via Bremsstrahlung
- Gold and diamond radiator for In/Coherent Bremsstrahlung
- Energy coverage: $0.2-0.95 E_0$
- Efficiency $\sim 80\%$
- Energy Resolution $\sim 10^{-3}$
- Timing Resolution ~ 100 ps

- ✱ Maximum photon energy of 5.7 GeV
 - $W_{\max} \sim 3.4$ GeV
 - $M_{\max} \sim 2.5$ GeV
- ✱ Beam intensity $10^7 \gamma/s$

Partial Wave Analysis

1) Isobar Model

e.g. 3π system

(a) resonance: X decay
 $X(2^{-+}) \rightarrow f_2(1275)\pi$

(b) isobar: $R_{\pi\pi}$ decay
 $f_2(1275) \rightarrow \pi\pi$

2) Moments+Dispersion Relations

e.g. 2π system

- 1) Moments of the angular distribution in term of partial waves

$$\langle Y_{\lambda\mu} \rangle(E_\gamma, t, M) = \frac{1}{\sqrt{4\pi}} \int d\Omega_\pi \frac{d\sigma}{dt dM d\Omega_\pi} Y_{\lambda\mu}(\Omega_\pi)$$

$$\langle Y_{00} \rangle = N [|S|^2 + |P_-|^2 + |P_0|^2 + |P_+|^2 + |D_-|^2 + |D_0|^2 + |D_+|^2 + |F_-|^2 + |F_0|^2 + |F_+|^2]$$

- 2) Parametrize partial waves in term of known $\pi\pi$ phase shift and unknown coefficients using Dispersion Relations
- 3) Derive partial wave cross sections to compare with models

PWA with Isobar Model

$$\gamma p \rightarrow \pi^+ \pi^+ \pi^- (n)$$

- Possible evidence of exotic meson $\pi_1(1600)$ in $\pi p \rightarrow (3\pi)^- p$ (E852-Brookhaven)
- Not confirmed in a re-analysis of a higher statistic sample
- New evidence recently reported by COMPASS

CLAS-g6C

- Clear evidence of non-exotic 2^{++} state $a_2(1320)$
- No-evidence of exotic 1^{+-} state $\pi_1(1600)$
- Relevance of baryon resonance background

**PWA in CLAS
is feasible!**

PWA: Moments+Dispersion Relations

$$\gamma p \rightarrow p \pi^+ \pi^-$$

- * Analysis of CLAS-g11 data
- * $M(\pi^+\pi^-)$ spectrum below 1.5 GeV:
 - P-wave: ρ meson
 - D-wave: $f_2(1270)$
 - S-wave: σ , $f_0(980)$ and $f_0(1320)$
- * Moments of the 2-pion angular distribution extracted via likelihood fit of data
- * Partial Wave fitted to experimental moments
- * **Known states well reproduced, e.g. $\rho(770)$**

First observation of $f_0(980)$ in photoproduction

$$3.4 \text{ GeV} < E_\gamma < 3.6 \text{ GeV}$$

$$0.5 \text{ GeV}^2 < -t < 0.6 \text{ GeV}^2$$

New High Statistics Photon run: g12

Search for new forms of hadronic matter in photoproduction on the proton

- Data taking completed in 2008
- Photon Energy up to 5.5 GeV
- More than 26 billion triggers (2-prong + 3-prong)
- Total Luminosity: 68 pb⁻¹
- Data processing completed and physics analysis in progress

Several exclusive channels are being analyzed

$$\gamma p \rightarrow \pi^+ \pi^+ \pi^- (n)$$

$$\gamma p \rightarrow K^+ K^+ \Xi^{*-} (1530)$$

$$\gamma p \rightarrow p K^+ K^- (\eta/\pi)$$

$$\gamma p \rightarrow p \pi^+ \pi^- (\eta)$$

$$\gamma p \rightarrow \pi^+ K^+ K^- (n)$$

$$\gamma p \rightarrow e^+ e^- p$$

...

- Cascade spectroscopy
- Search for exotic mesons
- Study of strangeonium states
- ...

EG6: Meson spectroscopy in coherent production on ^4He

- search for exotics in $\pi\eta$, $\pi\eta'$ final states
- 6 GeV electron beam on target on high pressure gas target
- scattered electron at "0" degrees $\rightarrow$ quasi-real photo-production
- recoiling nucleus detected in Radial TPC
- hadronic final state detected in CLAS
- data taking completed in fall 2009
- analysis in progress

Analysis of existing CLAS data shows clear peaks associated to known mesons in

- Radial TPC with 7atm He4 Target
- Solenoid for forward-focusing of Moeller electrons and bending of recoil nucleus in the TPC

$ep \rightarrow (e') p \pi^0 \eta$

- PbWO_4 calorimeter for improved photon acceptance at forward angles

The Technique works!!

12 GeV CEBAF

CLAS12

Forward Detector:

- TORUS magnet
- Forward SVT tracker
- HT Cherenkov Counter
- Drift chamber system
- LT Cherenkov Counter
- Forward ToF System
- Preshower calorimeter
- E.M. calorimeter

Central Detector:

- SOLENOID magnet
- Barrel Silicon Tracker
- Central Time-of-Flight

Proposed upgrades:

- Micromegas (CD)
- Neutron detector (CD)
- RICH detector (FD)
- Forward Tagger (FD)

Spectroscopy with CLAS12

The construction of a *Forward Tagger* has been proposed to continue the spectroscopy program with CLAS12 using quasi-real photoproduction

- electron scattering at “0” degrees (LowQ, post-target tagging)
- low- Q^2 virtual photon $\Leftrightarrow$ real photon (well known technique from high energy experiments)
- detection of the scattered electron allows to determine the photon energy and polarization
- knowledge of the photon energy and electron kinematics are important to select the exclusive final state
- polarization is essential to isolate the exclusive production mechanisms (M) and acts as a J^{PC} filter if M is known
- high luminosity on thin (gas)- targets
- Complementary technique to Hall-D Coherent Bremsstrahlung photon beam

A Forward Photon Tagger for CLAS12

Quasi-real photo-production with detection of scattered electrons at “0” degrees

- electron beam on target, scattered electrons at small angles are detected
- hadronic final state is detected in CLAS12
- photon linear polarization $\sim 65\% - 20\%$
- high electromagnetic background and radiation levels
- limited space

Forward Tagger

Electron detection via Calorimeter+Tracker+Veto for determination of energy and angles

- **calorimeter** to determine the electron energy with few % accuracy
- **tracker** to determine precisely the electron scattering plane and the photon polarization
- **veto** to distinguish electrons from photons and for fast triggering

PbWO4
Calorimeter
424 Crystals

Electron Detector

E'	0.5-4 GeV
ν	7-10.5 GeV
θ	2-5 deg
Q^2	0.007 – 0.3 GeV ²
Photon Flux	$5 \times 10^7 \gamma/s$ @ $L_e=10^{35}$
Rate	20 MHz @ $L_e=10^{35}$

Different hardware options:

Calorimeter:

- homogenous crystals (PbWO₄, LYSO, ...)
- sampling device (W+Fibers, W+Si, ...)

Tracker:

- gems, micromegas, ...

Veto:

- Plastic scintillator tiles, sci-fibers , ...

GEANT4 Simulations

A New Physics Program

A tagged photon beam in CLAS12 will open new possibilities for high quality physics beyond the already approved program:

- Meson spectroscopy
 - Spectroscopy on H target and search for exotics
 - Spectroscopy on ^4He and other gas targets
- Hadron spectroscopy
 - Heavy mass baryon resonances (Cascades and Ω^-)
- Compton scattering
- Meson polarizabilities
- J/ψ production close to threshold and on nuclear targets
- Large $-t$ physics

LOI-2010-001: "Hadron Spectroscopy with Low Q^2 electro-scattering in CLAS"

LOI-2010-004: "Production of the Strangest Baryon with CLAS12"

Endorsed by PAC35 and full proposal in preparation

Summary

Meson spectroscopy is a fundamental tool to study the properties of strong interaction

The present at CLAS

- Meson spectrum investigated in photoproduction
- PWA (IM and Moments + Dispersion relations) feasible in CLAS
- First results published, experimental program continues...

The future at CLAS12

- Experimental program can continue using quasi-real photoproduction
- A new forward tagger is being designed to detect scattered electrons down to 2 deg.
- High intensity (quasi)-real photon beam on proton and nuclear targets will give access to a rich physics program
- LOIs presented to PAC35 have been approved
- Full proposal is being prepared for January 2011

Search for Hybrid Mesons

Understanding the role of gluons and the origin of confinement is crucial to complete our picture of strong interaction

- At high energy experimental evidence is found in jet production
- At lower energies the hadron spectrum carries information about the gluons that bind quarks
- Can we find hints of the glue in the meson spectrum?

Search for non-standard states with explicit gluonic degrees of freedom

- Existence of these state is not prohibited by QCD but is not yet firmly established experimentally
- Finding clear evidence for hybrid mesons and determining their spectrum is of fundamental importance

Regular meson

Hybrid meson

CLAS12 – Design parameters

	Forward Detector	Central Detector
Angular range		
Tracks	$5^\circ - 40^\circ$	$35^\circ - 125^\circ$
Photons	$3^\circ - 40^\circ$	n.a.
Resolution		
$\delta p/p$ (%)	< 1 @ 5 GeV/c	< 5 @ 1.5 GeV/c
$\delta\theta$ (mr)	< 1	$< 10 - 20$
$\Delta\phi$ (mr)	< 3	< 5
Photon detection		
Energy (MeV)	> 150	n.a.
$\delta\theta$ (mr)	< 4 @ 1 GeV	n.a.
Neutron detection efficiency	< 0.7 (EC+PCAL)	n.a.
Particle ID		
e/π	Full range	n.a.
π/p	Full range	< 1.25 GeV/c
π/K	Full range	< 0.65 GeV/c
K/p	< 4 GeV/c	< 1.0 GeV/c
$\pi^0 \rightarrow \gamma\gamma$	Full range	n.a.
$\eta \rightarrow \gamma\gamma$	Full range	n.a.

12 GeV Schedule

- Oct '13: Hall A commissioning start
- Apr '14: Hall D commissioning start
- Oct '14: Hall B & C commissioning start