The GlueX Experiment
Search for Gluonic Hybrid Mesons via Photoproduction at Jefferson Lab

Paul Eugenio
Florida State University
Tallahassee, FL USA
Overview

- Motivation & QCD Exotics
- Identification of Exotic Mesons
- Photoproduction of Mesons
- The GlueX Experiment
  - Hybrid Meson Search at Jefferson Lab
  - Additional Physics with GlueX
Excitations of the flux tube can give rise to gluonic hybrid mesons.

LGT predicts lightest $J^{PC}=1^{+}$ exotics with mass of ~2 GeV.
Quark Model Meson Spectrum

\[ J = L + S \]

\[ S = 0, 1 \]

\[ L = 0, 1, 2, 3, \ldots \]

\[ \vec{J} = \vec{L} + \vec{S} \]

\[ P = (-1)^{L+1} \]

\[ C = (-1)^{L+S} \]

Meson quantum numbers characterized by given \( J^{PC} \)

**Allowed States:**

\[ J^{PC} = 0^{-+}, 0^{++}, 1^{--}, 1^{+-}, 1^{++}, 2^{--}, 2^{--}, 2^{++}, 2^{++}, \ldots \]

**Forbidden States (Exotics):**

\[ J^{PC} = 0^{+-}, 0^{--}, 1^{++}, 2^{--}, 3^{--}, 4^{--}, \ldots \]
The lightest hybrid meson nonet predicted by lattice QCD is $J^{PC} = 1^{-+}$.

Predicted hybrid meson mass region for experimental search: 1.5 GeV – 2.9 GeV.
**Gluonic Hybrid Decays**

Hybrid $\rightarrow q\bar{q}(L=1) + q\bar{q}(L=0)$

Hybrid $\leftrightarrow q\bar{q}(L=0) + q\bar{q}(L=0)$

**Favored decay modes**
- $b_1(1235)\pi$
- $f_1(1285)\pi$
- $a_2(1320)\pi$

**Forbidden/suppressed decay modes**
- $\pi\pi, \eta\pi, \rho\pi, \omega\pi, ...$

Photoproduction of Gluonic Excitations

- It has been pointed out\textsuperscript{1,2,3} that in the case of photoproduction exotic hybrids should be produced copiously.
- Recent lattice calculations show that the strength of charmonium hybrid radiative decays are similar to normal mesons\textsuperscript{4}

\begin{align*}
\text{quarks } J^{PC} \otimes \text{flux tubes } J^{PC} &= 1^-, 1^{++} \\
\text{quarks } J^{PC} \otimes \text{flux tubes } J^{PC} &= 0^+, 1^- \quad 2^+, \quad 0^{++}, 1^-, 2^{++}
\end{align*}

- Very little photoproduction data exists!

**Partial Wave Analysis**

*unraveling the bumps*

\[ I(\tau) = \sum_{k \in \epsilon'} \epsilon \epsilon' \rho \epsilon \epsilon' (\tau) \sum_{\alpha \alpha'}^{k \epsilon} V_{\alpha}^* A_{\alpha'}^*(\tau) k \epsilon V_{\alpha} \epsilon A_{\alpha}(\tau) \]

For unpolarized beam & target:

\[ I(\tau) = \frac{1}{2} \sum_{k \epsilon} \left| \sum_{\alpha}^{k \epsilon} V_{\alpha} \epsilon A_{\alpha}(\tau) \right|^2 \]

Complex parameters varied in the PWA to fit the data

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**Helicity Decay Amplitudes**

\[ A_{\alpha, M}(\tau) = A_{X}^{\lambda_1 \lambda_2; M} * A_{iso}^{\nu_1 \nu_2; \lambda_1} \ldots \]

\[ A_{X}^{\lambda_1 \lambda_2; M} = D_{\lambda M}^{J}(\theta, \phi) \frac{\tilde{L}}{J} (L 0; S \lambda | J \lambda) (S_1 \lambda_1; S_2 - \lambda_2 | S \lambda) K \]

\[ \epsilon A_{\alpha}(\tau) = a [A_{\alpha, M}(\tau) \pm b A_{\alpha, -M}(\tau)] \]

\[ \tilde{J} = \sqrt{J(J+1)} \]

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**Wigner D-functions**

**Clebsch-Gordan Coefficients**

**Mass Dependent Factor**
Partial Wave Analysis

Step 1: Decompose to Partial Waves

\[ X \rightarrow p_1 + p_2 + p_3 + \ldots \]

Bin by Bin Likelihood Analysis
Partial Wave Analysis

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\[ X \rightarrow p_1 + p_2 + p_3 + \ldots \]

**Bin by Bin Likelihood Analysis**
Partial Wave Analysis
Step 2: Extract Resonance Parameters

Mass Dependent Analysis
Observation of Exotic $\pi_1(1600)$

$\pi_1(1600) \rightarrow \eta'\pi$

BNL-E852

$\pi^- p \rightarrow p \eta' \pi^-$
Several Exotic Candidates Exist

Have we observed an Exotic Multi-Quark?

\[ \pi_1(1400) \]

\[ \pi_0(1400) \]

\[ \pi_1(1600) \]

Have we observed a Gluonic Hybrid?

\[ \pi_1(1600) \]

\[ d\bar{s}g \]

\[ u\bar{s}g \]

\[ d\bar{u}g \]

\[ u\bar{d}g \]

But there is a rich history of controversy

Multiplet 17

\[ \pi_1(2000) \]

\[ d\bar{u}g \]

\[ u\bar{d}g \]

\[ s\bar{u}g \]

\[ s\bar{d}g \]

\[ \pi_1(1900) \]
Not Outrageous, but not great agreement

\[ \pi^- p \rightarrow p X^- \]

All observation are from neutral exchange reactions
Non-observation of \( \pi_1(1600) \) in charge exchange photoproduction is consistent with exotic production via Pomeron; however, \( \pi_1(1600) \to \rho \pi \) but not \( \rho \pi \to \pi_1(1600) \).
GlueX Experiment

Goal: map the spectrum of exotic hybrid mesons

Method: Photo-produce hybrids off proton target and identify the quantum states using Partial Wave Analysis of decay product distributions

\[ \vec{\gamma} + p \rightarrow p + X \]

- 9 GeV linearly hybrid polarized meson
- \[ \vec{\gamma} + p \rightarrow p + X \]

detectable final state
- 5π + 1p
  - (mixed charged and neutral)
  - 5π + 1p

DETECTOR DESIGNED FOR PWA
Jefferson Lab 12 GeV Upgrade

April Fall 2014 Beam Commissioning

The Hall D
Polarization

- Linear polarization enables one to identify the naturality of the production exchange.

- Photon Polarization:
  - 20 μm diamond radiator
  - Coherent peak is linearly polarized
  - ~40% polarization with peak @ 9GeV
  - Peak location tunable with diamond angle

- cohererent bremsstrahlung spectrum

\[ \delta E/E = 0.1\% \]
\[ \text{Pol} = 40\% \]
Barrel Calorimeter

191 layer Pb-scintillating fiber sandwich
  15.5\text{x}_0
  12.5\% sampling fraction
  1152 + 192 = 1344 readout sections/end
  \( \sigma_E/E = (5.54/\sqrt{E}) \times 1.6 \% \)
  \( \sigma_z = 5\text{mm}/\sqrt{E} \)
  \( \sigma_t = 74\text{ps}/\sqrt{E} \times 33\text{ps} \)
  angular coverage \( 11^\circ < \theta < 120^\circ \)

BCAL has 2-ended readout allowing one to reconstruct in 3-D
Lead Glass Calorimeter:
- 2800 F8–00 and F108 (center) Pb–glass blocks
- 4cm x 4cm x 45cm
- $\sigma_E/E = (5.7/\sqrt{E} \pm 2.0)\%$
- $\sigma_{xy} = 6.4\text{mm}/\sqrt{E}$
- angular coverage $2^\circ < \theta < 11^\circ$
Charged Particle Tracking
central & forward drift chambers

Central Drift Chamber:
- 3522 straw tubes (1.6cm diameter)
- 12 axial layers, 16 stereo layers (6°)
- $dE/dx$ for $p < 450$ MeV/c
- $\sigma_r = 150\mu m$
- angular coverage $6^\circ < \theta < 155^\circ$

$\sigma_p / p : 1.5 - 3.0\%$

Forward Drift Chamber:
- 4 packages, 6 planes/package, 96 wires/plane (2304 sense wires)
- cathode strip readout (48 planes x 216 strips/plane = 10,368 strips)
- $\sigma_r = \sim 200\mu m$ perpendicular to wire (drift time)
- $\sigma_s = \sim 200\mu m$ along wire (cathode strips)
- angular coverage $1^\circ < \theta < 30^\circ$

FDC chamber construction
Particle Identification
Time-of-flight & dE/dx

- \( \sigma_{\text{TOF}} \) < \( 80/\sqrt{2} \) ps
- \( \pi p \) separation < 450 MeV/c
- \( \pi K \) separation < 275 MeV/c
- \( \sigma_t = 74 \text{ps} / \sqrt{E} + 33 \text{ps} \)

PID upgrade plans are underway

- 168 modules
- \( \sigma_{\text{TOF}} < 80/\sqrt{2} \) ps
- \( \pi K \) separation < 2GeV/c

Start Counter
- 40 scintillators
- 300 ps (w/tracking)
- Used for start-up
GlueX Acceptance

GlueX
High, and reasonably uniform Acceptance up to 2.5 GeV/c².

Sensitive to charged particles And photons.

Some particle ID in the initial phases, plans to upgrade PID.

Able to fully reconstruct the 4-12 Particle final states.
Additional Physics with GlueX

- Cascade Spectroscopy
- Search for Excited Strange Mesons & Hidden Strange Mesons
- PrimEx at 12 GeV
  - Measurement of $\Gamma(\eta \rightarrow \gamma\gamma)$ via Primakoff Effect
The Quark Model of hadrons works surprisingly well, yet QCD allows for a much richer spectrum of hadronic matter.

The excitation of the gluonic fields leads to an entirely new spectrum of mesons._

- Several promising exotic candidates exist
- Exotic hybrids should be copiously produced via photoproduction
  - Virtually unexplored production

The JLAB GlueX program plans to firmly identify and map out the exotic spectrum

- Jlab 12 GeV Upgrade Project is near completion
- Beam on Target in Fall 2014!
- New Collaborators Welcome