Light-Meson Spectroscopy at GlueX

Alexander Austregesilo
for the GlueX Collaboration

21st Particles and Nuclei International Conference (PANIC 2017)
Beijing, China
September 2nd, 2017
Outline

1. Motivation
2. First Results
   - Beam Asymmetries
   - Prospects for Spectroscopy
   - Charmonium
3. Summary
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2. First Results
   - Beam Asymmetries
   - Prospects for Spectroscopy
   - Charmonium

3. Summary
Context: Strong Interaction

Quantum ChromoDynamics (QCD)

- Degrees of freedom: quarks and gluons
- Confinement: only color-neutral objects can be observed
- Baryons ($qqq$, $\bar{q}\bar{q}\bar{q}$) and Mesons ($q\bar{q}$) as the relevant degrees of freedom
Context: Strong Interaction

Quantum ChromoDynamics (QCD)

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- Baryons \((qqq, \bar{q}\bar{q}\bar{q})\) and Mesons \((q\bar{q})\) as the relevant degrees of freedom
- Glueballs, Hybrids and other exotic hadrons predicted by many approximations

Gell-Mann’s Totalitarian Principle: Everything not forbidden is compulsory!
Motivation

Meson Spectroscopy

Constituent Quark Model (CQM)
- Bound state of $q\bar{q}$
- Quantum numbers: $I^G(J^{PC})$

Light-Meson Spectroscopy
- Exotic quantum numbers $(0^{--}, 0^{+-}, 1^{--}, ...)$ forbidden by NR QM
- Many missing and disputed states
- Broad and overlapping resonances

⇒ Study spectrum and properties (width, decay, ...) of mesons

$q\bar{q}$
$(q\bar{q}), (q\bar{q})_0$
$(q\bar{q})(q\bar{q})$
$(q\bar{q})_8g$
Hybrid
$gg$
Glueball

A. Austregesilo (aaustreg@jlab.org) — Light-Meson Spectroscopy at GlueX
Tremendous progress in recent years

- Excited states, spin-identified spectra, chromomagnetic content
- Resonance parameters and decay modes starting to become accessible
- Experimental results need to reach equivalent precision
Spectroscopy Worldwide

hadron probes

colliding beam

CDF

ATLAS

CMS

LHCb

ongoing/future

BES III

BaBar

Belle II

completed/analysis

fixed target

COMPASS

Panda

ongoing/future

GlueX

CLAS12

completed/analysis
Photoproduction

\[ \gamma \rightarrow (\rho, \omega, \phi) \rightarrow X \]

\[ P, \pi, \rho, \ldots \]

\[ p \rightarrow p, n, \Delta, \ldots \]

Complementary Production Mechanism

- Photon coupling via vector meson dominance
- Wide variety of \( I^G J^{PC} \) states accessible
- Photon polarization provides additional constraints

Exchange | Exotic Final States
--- | ---
\( \rho \rightarrow 0^{++} \) | \( b, h, h' \rightarrow 2^{+-}, 0^{+-} \)
\( \pi^0 \rightarrow 0^{-+} \) | \( b_2, h_2, h'_2 \rightarrow 2^{+-} \)
\( \pi^\pm \rightarrow 0^{-+} \) | \( \pi_1 \rightarrow 1^{--} \)
\( \omega \rightarrow 1^{--} \) | \( \pi_1, \eta_1, \eta'_1 \rightarrow 1^{--} \)
**Photon Beam Line**

**Motivation**

**Results**

**Summary**

### 12 GeV e⁻

North LINAC

East ARC

### Photon Tagger

### Pair Spectrometer & Triplet Polarimeter

### 9 GeV Polarized Photon Beam

- Coherent Bremsstrahlung on thin diamond
- Energy tagged by scattered electrons
- Collimator to suppress incoherent part
- Linear polarization in peak $P_\gamma \approx 40\%$, measured by Triplet polarimeter: $\gamma e^- \rightarrow e^- e^+ e^-$
- Beam intensity: $1 - 5 \cdot 10^7 \gamma$/s in peak
Map light quark meson spectrum up to 3 GeV/c² with full acceptance for all decay modes.
GlueX Runs

Fall 2014 - Spring 2015
Detector and beamline commissioning

Spring 2016: GlueX Engineering Run
- Initial physics data ($\approx 80$ h)
- First results presented here

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Graph:
- Number of Events Collected / 10^9 vs. Integrated Beam Time [Days]
- Lines for $\perp$ Polarization, $\parallel$ Polarization, Unpolarized, Total

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GlueX Runs

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**GlueX-I: 2017 - 2018**
- 6 weeks in spring 2017
- 20% of full data set collected ($\approx 1$PB)
- Will continue early 2018

**GlueX-II: 2019+**
- Upgraded detector
- High luminosity
Motivation

Results

Summary

Analysis Strategy

GlueX + Joint Physics Analysis Center (JPAC)

- High statistical precision requires removing simplifying assumptions
- Robust theoretical models and capable analysis frameworks
- Collaboration: experiment and theory working together on analysis and interpretation

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Motivation

Understanding production mechanism necessary for amplitude analysis

Beam asymmetry $\Sigma$ and its $t$ dependence sensitive to exchanged $J^{PC}$

Beam polarization $P_\gamma$ measured with polarimeter

Cancel systematic effects by rotating polarization plane by 90°
π0 and η Beam Asymmetries

First GlueX Publication!

- No observed dip at \(-t = 0.5 \text{ (GeV}/c)^2\)
- Comparison with several theory models
- Constrains background to baryon resonance production
- First measurement for η at this energy
- Measurement for η' with 2017 data

Recently revived interest in charge exchange

$-t$ dependence sensitive to Regge contributions

Important confirmation for theoretical models

**Motivation**

**Results**

**Summary**

$\pi^+/\pi^-$ Beam Asymmetry

**SLAC data**

from [PRD 20 (1979) 1553]
**Motivation**

Recently revived interest in charge exchange $t$-dependence sensitive to Regge contributions.

**Results**

*Important confirmation for theoretical models*

- $\chi^2 / \text{ndf} = 983.5 / 416$
- $C_{BW} = 608.9 \pm 4.7$
- $M_0 = 1.22 \pm 0.00$
- $\Gamma_0 = 0.1106 \pm 0.0015$
- $C_{PS} = 110.9 \pm 5.8$

\begin{align*}
\frac{S}{S+B} &= 0.921 \\
\end{align*}

**Summary**

- Preliminary

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**Beam Asymmetry**

$\pi^+ / \pi^-$ Beam Asymmetry

$\Delta^{++}(1232)$

$\gamma \rightarrow \Delta^{++}(1232)$

- $M_0 = 1.59 \pm 0.00$
- $\Gamma_0 = 0.15 \pm 0.00$
- $C_{PS} = 55.1 \pm 0.4$

\begin{align*}
\frac{S}{S+B} &= 0.921 \\
\end{align*}


Artifacts of tracking detector geometry

Motivation  Results  Summary

\(\rho\) Beam Asymmetry

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

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

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

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Motivation

Results

Summary

**ρ Beam Asymmetry**

Artifacts of tracking detector geometry

- Acceptance effects cancel
- Confirmation of polarization
- Analysis of angular distribution
  ⇒ Spin Density Matrix Elements

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Motivation

Results

Summary

\( \pi\pi \) Spectroscopy

\[ \text{Invariant Mass (GeV/c)} \]

\[ \text{# Combos / 2.5 MeV/c} \]

\[ \approx 100 \times \] more data than previous experiments

Hints for excited \( \rho \) \( \Rightarrow \) moment / amplitude analysis started

\[ \text{SLAC [PRL 53 (1984) 751]} \]
Multi-Photon Final States
\( \gamma + p \rightarrow 4\gamma + p \)

Motivation

Results

Summary

\( m(2\gamma,\text{pair}2) \) vs \( m(2\gamma,\text{pair}1) \)

\( \pi^0\eta \)

\( \pi^0 \pi^0 \)

\( \pi^0 \eta \)

\( \eta \pi^0 \) invariant mass

\( f_2(1270) \)

\( f_0(980) \)

\( a_0(980) \) \( a_2(1320) \)

Combinations / 0.0025 GeV

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Motivation Results Summary

Multi-Photon Final States
\( \gamma + p \rightarrow 5 \gamma + p \)

\[
\begin{align*}
\Delta M(\pi^0\gamma) &= 0.76 - 0.81 \text{ GeV} \\
\omega(782) &+ b_1(1235)
\end{align*}
\]
Motivation

Results

Summary

Multi-Photon Final States

\[ \gamma + p \rightarrow 6\gamma + p \]

- **GlueX** well equipped for the detection of **neutral particles**
- Excellent prospects for spectroscopy program

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Mapping the Meson Spectrum

Motivation

Results

Summary

Mapping the Meson Spectrum

- **negative parity**
  - $\rho'$
  - $b_1(1235)$

- **positive parity**
  - $\alpha_2(1320)$
  - $f_2(1270)$

- **exotics**

**Meson Mass (MeV)**

$J^{PC}$

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J.J. Dudek et al. [Phys. Rev. D 88 (2013)]
Charmonium Photoproduction

\[ \gamma + p \rightarrow p + J/\psi, \quad J/\psi \rightarrow e^+ e^- \]

- Production at threshold is ideal for studying N + J/ψ interaction
- Very few existing measurements
Charmonium Photoproduction

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- Production at threshold is ideal for studying N + J/\psi interaction
- Very few existing measurements
- First observation of charmonium at 12 GeV CEBAF
Summary

Status

- Successful **commissioning** and **early physics** analyses
- 20% of data for GlueX-I **taken**
- Understanding of detector **acceptance** and **systematics**
  ⇒ Comparison with previous measurements and models
- Study **production mechanism**
  ⇒ Cross sections, beam asymmetries and spin density matrix elements

GlueX-I: **Light-Meson Spectroscopy**

- **Mapping** of the entire light meson spectrum
- **Precise measurement** of known resonances and ultimately hybrid candidates

Plans with GlueX-II: **Strange-Meson Spectroscopy**

- Focus on meson spectrum with **strangeness** content
Motivation

Results

Summary

GlueX-II Detector Upgrade

GlueX DIRC: construction started with BaBar DIRC components for $\pi/K$ separation up to 4 GeV/c

⇒ Strange-meson spectroscopy

High luminosity: high-level trigger

⇒ Rare processes

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GlueX-II Detector Upgrade

- **GlueX DIRC**: construction started with BaBar DIRC components for $\pi/K$ separation up to 4 GeV/c
  $\Rightarrow$ Strange-meson spectroscopy

- **High luminosity**: high-level trigger
  $\Rightarrow$ Rare processes

Thank you for your attention!