Meson Spectroscopy program at CLAS12

Nicholas Zachariou
(CLAS collaboration)
Outline

• Why spectroscopy of mesons?

• Jefferson Lab

• CLAS12 and the Forward Tagger

• MesonEX @ CLAS12
Why Meson Spectroscopy?

• QCD well understood in the high-energy, perturbative regime

• Understanding the dof in the non-perturbative regime is challenging
  • What is the role of gluons?
  • What is the origin of quark confinement?

• Measuring the spectrum of hadrons allows a comprehensive understanding of the strong force
Why Meson Spectroscopy?

• Mesons → Simplest bound system to study
• QCD does not prohibit the existence of unconventional meson states -- *hybrids* (*qqg*), *tetraquarks* (*qqqq*), and *glueballs*.
  • Identification can be difficult → mix with ordinary states
  • Unique signature: Exotic quantum numbers
What has been done already?

• Various approaches including hadron production, NN annihilation, ...

• Photoproduction – Limited due to low-quality/luminosity experiments
  • Exotic $J^{PC}$ more likely to be produced by $S=1$ probe
  • Polarised beams can simplify extraction of Partial Waves
  • Production rates for exotics comparable to regular mesons

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

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

A. Afanasev and P. Page et al. PR A57 1998 6771
A. Szczepaniak and M. Swat PLB 516 2001 72

regular mesons @ $E_\gamma = 5$GeV
$X = a_2$

Exotic meson @ $E_\gamma = 8$GeV
$X = \pi_1(1600)$
Thomas Jefferson Laboratory

• CEBAF Accelerator
• Recently upgraded to 12 GeV electron beams
  • 4 experimental halls
  • Racetrack accelerator (LINACs) allowing multi-pass beam acceleration
  • High-quality beams ~100% duty cycle
  • Highly polarized beams ~80%
  • High currents up to 100 μA (Halls A and C)
CEBAF Large Acceptance Spectrometer

- CLAS12 provides an efficient detection of charge and neutral tracks
  - Based on solenoid (CD) and toroidal (FD) magnetic fields
  - Excellent for multi-particle final states
  - Excellent PID: TOF, Cerenkov, RICH (charged), calorimeter (neutral)

Nominal Luminosity: \( L = 10^{35} \text{ cm}^{-2} \text{ s}^{-1} \)
Momentum resolution (FD): \( \frac{dp}{p} < 1\% \)
\( \Theta \) resolution = 1 mrad
\( \Phi \) resolution = 1 mrad/sin \( \Theta \)
Timing resolution TOF = 100 ps

\( \pi/K \) separation: 4\( \sigma \) separation up to 2.8 GeV
\( K/p \) separation: 4\( \sigma \) separation up to 4.8 GeV
\( \pi/p \) separation: 4\( \sigma \) separation up to 5.4 GeV
The Forward Tagger

• Installed July 2017
• Composed of:
  • Tracker
  • Scintillation Hodoscope
  • Calorimeter


<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>DESIGN VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>FT-Cal</td>
<td></td>
</tr>
<tr>
<td>Calorimeter type</td>
<td>PbWO4, homogeneous</td>
</tr>
<tr>
<td>Crystal number and size</td>
<td>332, 15x15x200 mm³</td>
</tr>
<tr>
<td>Readout sensors</td>
<td>Hamamatsu LAAPD s8664-1010</td>
</tr>
<tr>
<td>Working Temperature</td>
<td>T = (0 – 18) °C (ΔT ≤ 0.1 °C)</td>
</tr>
<tr>
<td>FT-Trck</td>
<td></td>
</tr>
<tr>
<td>Tracking technology</td>
<td>two double-layers, bi-face bulk MicroMega</td>
</tr>
<tr>
<td>Detector type</td>
<td>Strips, 3392 channels</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>ΔX, ΔY ≤ 150 μm</td>
</tr>
<tr>
<td>FT-Hodo</td>
<td></td>
</tr>
<tr>
<td>Detector technology</td>
<td>2 layers of plastic scintillator tiles</td>
</tr>
<tr>
<td>Tiles number and size</td>
<td>74 (30x30x15 mm³) + 42 (15x15x7 mm³)</td>
</tr>
<tr>
<td>Readout sensors</td>
<td>Hamamatsu SiPM S10362-100</td>
</tr>
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</table>

Expected Performance

<table>
<thead>
<tr>
<th>VALUE</th>
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<tbody>
<tr>
<td>Azimuthal angular coverage</td>
</tr>
<tr>
<td>EM shower energy range</td>
</tr>
<tr>
<td>Energy resolution</td>
</tr>
<tr>
<td>Angular resolution</td>
</tr>
<tr>
<td>Time resolution</td>
</tr>
</tbody>
</table>
MesonX Experiment

- Quasi-real photoproduction on proton target
  - Detail study of light-quark meson spectrum (1.0 – 3.0 GeV)
  - Determine masses and properties of rare qq states
  - Search and identify exotic mesons

- Data collection started in 2018
- ~50% of the allocated beam time already carried out
- Dedicated trigger - coincidence on FT EM shower + 2 charged hadrons in CLAS12

<table>
<thead>
<tr>
<th>Forward Tagger</th>
<th></th>
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<tbody>
<tr>
<td>E'</td>
<td>0.5-4.5 GeV</td>
</tr>
<tr>
<td>ν</td>
<td>7-10.5 GeV</td>
</tr>
<tr>
<td>θ</td>
<td>2.5-4.5 deg</td>
</tr>
<tr>
<td>Q²</td>
<td>0.007 – 0.3 GeV²</td>
</tr>
<tr>
<td>W</td>
<td>3.6-4.5 GeV</td>
</tr>
<tr>
<td>Photon Flux</td>
<td>5 x 10^7 γ/s @ L_e=10^{35}</td>
</tr>
</tbody>
</table>
Meson Experiment

- Expected results
  - Isobar model 3πi production

<table>
<thead>
<tr>
<th>State</th>
<th>JPC</th>
<th>L</th>
<th>Decay Mode</th>
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<tbody>
<tr>
<td>a1 (1260)</td>
<td>1++</td>
<td>D</td>
<td>ρπ</td>
</tr>
<tr>
<td>a2 (1320)</td>
<td>2++</td>
<td>D</td>
<td>ρπ</td>
</tr>
<tr>
<td>π2 (1670)</td>
<td>2−+</td>
<td>P</td>
<td>ρπ</td>
</tr>
<tr>
<td>π2 (1670)</td>
<td>2−+</td>
<td>F</td>
<td>ρπ</td>
</tr>
<tr>
<td>π2 (1670)</td>
<td>2−+</td>
<td>S</td>
<td>f2π</td>
</tr>
<tr>
<td>π2 (1670)</td>
<td>2−+</td>
<td>D</td>
<td>f2π</td>
</tr>
<tr>
<td>π1 (1600)</td>
<td>1−+</td>
<td>P</td>
<td>ρπ</td>
</tr>
</tbody>
</table>

σ_{tot} \approx 10\mu\text{barn}

Leakage contribution to exotic waves from others: < 1%

Black: generated, Red: t=-0.5 GeV², Blue: t=-0.2 GeV² (D. Glazier, U. Glasgow)
Meson Experiment

• First look at FT data
• Energy Calibrations on $\pi^0$ 2-photon decay
• Timing calibration exceed specifications (300 ps)
• Energy resolution $\sim 3\% @ 2\text{GeV}$ still $+1\%$ higher than specs

*- Lucilla Lanza & Raffaella DeVita*
Meson Experiment – First analysis

\[ \gamma p \to p\pi^0 \]

- Inconsistent results between GlueX and SLAC
- CLAS12 - Reconstruction of reaction from \( \pi^0 \) and \( e' \) in FT
- Straightforward determination of \( \Sigma \) and \( d\sigma/dt \)
- Results expected early 2022

L. Biondo Messina U.
Meson Experiment – Benchmark reaction
\[ \bar{\gamma}p \rightarrow \rho\pi^+\pi^- \]

- Fully exclusive reaction
- Determination of moments
  - Phys. Rev. D 100, 054017
- Moments fit using 2pi decay angles as a function of 2pi mass
- Technique successfully applied to CLAS6 data:
  - PHYSICAL REVIEW D 80, 072005 (2009)
  - PHYSICAL REVIEW D 98, 052009 (2018)
Meson Experiment

$\bar{\gamma}p \rightarrow pK^+K^-$

Analysis procedure is identical to 2 pion channel

Exclusivity of the reaction allows clean(er) signal

Rich mass spectrum observed

Next steps: Study of angular distribution in 2K system
Meson Experiment – Exotic search

\[ \bar{\gamma}p \rightarrow \pi^+ \pi^+ \pi^- n \]

- Key reaction for exotic search
- Missing-mass technique with 3 pion ID
- Background significant but contributions understood

First fits to 3 body final state via 4 decay angles have been done on small data set
Summary

• Recent developments in accelerator and detector advancements allow the detailed study of meson spectrum via photoproduction experiments

• MesonX aims at searching for exotic mesons and studying in detail the light-quark meson spectrum up to masses of 2.5 GeV.

• Data analysis well underway (50% of statistics)

• First results expected in 2022