Hadron Spectroscopy and the CLAS12 Forward Tagger

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Why Hadron Spectroscopy

• QCD is responsible for most of the mass of matter that surrounds us
• Understanding the origin of this mass, i.e. the mass of hadrons, is a necessary step to reach a deep understanding of QCD
  - Revealing the nature of the mass of the hadrons
  - Identify the relevant degrees of freedom
  - Understand the role of gluons
  - Investigate the origin of confinement
• Hadron spectroscopy is a key tool to investigate these topics

Mesons & Baryons

π

p

Effective Degrees of Freedom

Quarks and Gluons

<< 0.1 fm

0.1 – 1 fm

> 1 fm

Mesons & Baryons
The construction of a *Low Q Tagging Facility* or *Forward Tagger* has been proposed to launch a spectroscopy program with CLAS12 using quasi-real photo-production

- Electron scattering at “0” degrees (2.5° - 4.5°)
  - low $Q^2$ virtual photon ↔ real photon
- Photon tagged by detecting the scattered electron at low angles
  - high energy photons $6.5 < E_\gamma < 10.5$ GeV
- Quasi-real photons are linearly polarized
  - polarization ~ 70% - 10% (measured event-by-event)
- High Luminosity (unique opportunity to run thin gas target!)
  - Equivalent photon flux $N_\gamma \sim 5 \times 10^8$ on 5-cm $H_2$
    ($L=10^{35}$ cm$^{-2}$s$^{-1}$)
- Multiparticle hadronic states detected in CLAS12
- High resolution and excellent PID (kaon identification)
- Complementary to tagged Bremsstrahlung photon beam
Forward Detector:
- TORUS magnet
- Forward SVT tracker
- HT Cherenkov Counter
- Drift chamber system
- LT Cherenkov Counter
- Forward ToF System
- Preshower calorimeter
- E.M. calorimeter (EC)

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

Proposed upgrades:
- Micromegas (CD)
- Neutron detector (CD)
- RICH detector (FD)
- Forward Tagger (FD)
The CLAS12 Forward Tagger
The CLAS12 Forward Tagger

Electron detection via **Calorimeter + Tracker + Veto** proposed by INFN, JLab, CEA-Saclay, U. Edinburgh, U. Glasgow, JMU, NSU, Ohio U.

- *calorimeter* to determine the electron energy with few % accuracy → homogenous PbWO₄ crystals
- *tracker* to determine precisely the electron scattering plane and the photon polarization → micromegas
- *veto* to distinguish photons from electrons → scintillator tiles with WLS fiber readout

<table>
<thead>
<tr>
<th><strong>Forward Tagger</strong></th>
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<tbody>
<tr>
<td>E’</td>
<td>0.5-4.5 GeV</td>
</tr>
<tr>
<td>v</td>
<td>6.5-10.5 GeV</td>
</tr>
<tr>
<td>θ</td>
<td>2.5°-4.5°</td>
</tr>
<tr>
<td>Q²</td>
<td>0.007 – 0.3 GeV²</td>
</tr>
<tr>
<td>W²</td>
<td>3.6-4.5 GeV</td>
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<tr>
<td>Photon Flux</td>
<td>$5 \times 10^8 \gamma/s @ L_e=10^{35}$</td>
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The CLAS12 Forward Tagger

- Tracker electronic boxes
- Inner tungsten pipe
- Main support pipe
- Tracker
- Calorimeter
- Hodoscope
- Tungsten cone
FT Calorimeter

**Technology:**
- PbWO-II Crystals: 332 elements, 15x15x200 mm³
- Readout based on Hamamatsu LAAPD s8664-1010
- Custom FEE: IPN-Orsay preamplifiers
- Operating temperature: 0 °C

**Performance:**
- Energy range:
  - 5 MeV (threshold on single crystal) to 8 GeV
- Angular range:
  - 2.5°-4.5°
- Energy resolution:
  - $2.3\%/\sqrt{E(\text{GeV})} \oplus 0.5\%$
FT Hodoscope

Technology:
• Plastic Scintillator tiles: 2 layers with 116 elements, 30x30 and 15x15 mm²
• Readout based on WLS fibers coupled to Hamamatsu 3x3 mm² SiPMs
• Custom FEE: INFN-Genova preamplifiers

Performance:
• > 20 p.e. measured on 15x15 tile (4-mm thickness)
• > 30 p.e. measured on 30x30 tile (4-mm thickness)
**Technology:**
- Two double layers of bi-face bulk Micromegas with 500 μm strip readout
- Custom FE electronics (CEA): 3392 channels, based on DREAM Asic
- Same technology adopted for CLAS12 central tracker

**Performance:**
- Spatial resolution: < 150 μm
- Angular resolution < 0.2° in θ and <3° in φ
FT Calorimeter Assembly

- Each crystal will be encased in a self-supporting structure;
- Two copper plate at the end of the calorimeter will provide positioning and load path for the cristals;
• Each crystal will be wrapped in Vikuiti VM200 film.
• The crystals will be aligned to the rear copper plate via a pin in the downstream peek support will have a pin to align crystal.
• The upstream peak support will have a protrusion to be fixed onto the front copper plate.
• The inner and outer copper shields will provide thermal shielding for the crystals assembly
• A net of pipes clamped and glued to the copper shield will provide cooling and temperature stabilization for the calorimeter
FT Calorimeter Assembly

• APDs preamplifiers will be independently removable without disassembling the calorimeter
• A single motherboard will provide the power supply and collect signal from all the amplifiers
• FT can operate both horizontally and vertically
• This structure has been validated with a prototype
The calorimeter and the inner tungsten pipe will be pre-assembled before the installation.

The calorimeter’s weight (~350 kg) will be transferred to the inner tungsten pipe via peek supports.

Shaped insulation will be inserted between the inner copper shield and inner tungsten pipe.

The calorimeter will be covered by insulator to provide the temperature stability.

A carbon fiber skin will enclose the calorimeter, sealing the system from the outside.
The Meson-Ex experiment

Exp-11-005
M.Battaglieri, R.De Vita, D.Glazier, C.Salgado, S.Stepanyan, D.Weygand and the CLAS Collaboration

Study the meson spectrum in the 1-3 GeV mass range to identify gluonic excitation of mesons (hybrids) and other quark configuration beyond the CQM

★ Hybrid mesons and Exotics
  - Search for hybrids looking at several different final states
  - Charged and neutral decay modes
    - $\gamma p \rightarrow n3\pi, \gamma p \rightarrow p\eta\pi, ...$

★ Hybrids with hidden strangeness and strangeonia
  - Intermediate mass of s quarks links long to short distance QCD potential
  - Good resolution and kaon I3d required
    - $\gamma p \rightarrow p\phi\pi, \gamma p \rightarrow p\eta\pi, \gamma p \rightarrow p2K\pi, ...$

★ Scalar Mesons
  - Poorly know $f_0$ and $a_0$ mesons in the mass range 1-2 GeV
  - Theoretical indications of unconventional configurations (qqqq or gg)
    - $\gamma p \rightarrow p2\pi, \gamma p \rightarrow p2K, ...$

One of the most important fields in hadron physics and main motivation for the JLab 12 GeV upgrade
Search for Strangeonia in CLAS12

\[ \gamma p \rightarrow pX(M=1480, \Gamma=130\text{ MeV}) \]
\[ \rightarrow p\varphi\pi^0 \rightarrow p K^+(K^-)\gamma\gamma \]

- Unusual BR in \(\varphi\pi\) (OZI suppressed)
- \(J^{PC}=1^{--}\) \(\sigma \sim 10\text{nb}\)
- Tetra-quarks or hybrid
- CLAS12 acceptance \(\sim 10\%\)
- High-\(p\) K id relies on kin-fit
- \(K/\pi\) separation for \(p<2.6\text{ GeV/c}\)

K/\pi separation up to \(p=2.6\text{ GeV/c}\)
Search for hybrids in the $3\pi$ channel

\[ \gamma p \rightarrow nX \rightarrow n\pi^+\pi^+\pi^- \]

- Possible evidence of exotic meson $\pi_1(1600)$ in $\pi^0 p \rightarrow (3\pi)^0 p$ (E852-Brookhaven)
- Not confirmed in a re-analysis of a higher statistic sample
- New evidence recently reported by Compass

**Expected yield 20d run**

\[ \gamma p \rightarrow (n)\pi^+\pi^+\pi^- \]

CLAS12 expected results:
- Good acceptance for resonance masses in the range 1.4-2.4 GeV
- Broad angular coverage in the resonance decay angles
- Large statistics expected with limited run time
In preparation for the experiment, **PWA tools** are being developed and tested on pseudo data (Monte Carlo) for different reactions as $\gamma p \rightarrow n\pi^+\pi^+\pi^-$

- Test for 2 t bins:
  - line: generated wave
  - $|t|=0.2$ GeV$^2$
  - $|t|=0.5$ GeV$^2$

As a function of $M_{3\pi}$

The CLAS12 detector system is intrinsically capable of meson spectroscopy measurements.
Future Developments

The completion of CLAS12+FT installation is foreseen for fall 2015 and the beginning of data taking on proton target early 2016

Next generation experiment with improved-extended equipment:

- Extension of physics program with full momentum angular range particle identification
- Improvement of CLAS12 acceptance for neutrals with addition of dedicated calorimeters
- Development of dedicated trigger hardware for efficient and fast selection of multi-particle final states
- Extension of spectroscopy program to thin targets
Meson spectroscopy in coherent production on $^4\text{He}$

- Use coherent quasi-real production on nuclei ($^4\text{He}$) as spin and isospin filter
  - Suppress s-channel baryon resonance background
  - Results in simpler PWA: $S=I=0$ target acts as a filter on final state waves
  - Low Q electron-scattering results in high luminosity on thin gas target
- Requires detection of recoiling nucleus → Radial Time Project Chamber
- Tested on key reactions for the hybrid search ($\gamma^4\text{He}\rightarrow^4\text{He}\pi\eta,\gamma^4\text{He}\rightarrow^4\text{He}\pi\eta'$)
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Worldwide collaboration with experimental and theoretical groups for the development of new analysis tools:
- HAdron SPEctroscopy analysis CenTer (Haspect) in Genova
- Jefferson Lab analysis center
- International workshops (INT2009, ECT*2011, ATHOS 2012, ...)

Summary

- Spectroscopy is a key field for the understanding of fundamental questions in hadronic physics and is one of the driving forces for the JLab 12GeV upgrade

- A new detector, the Forward Tagger, is being built to detect the scattered electron at small angle and perform quasi-real photoproduction experiment

- A broad physics program to study meson spectroscopy in the light quark sector and search for exotic has been launched

- Second generation experiments, exploiting new and improved detection capabilities are foreseen