Forward photon tagging facility

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**and the CLAS Collaboration**
Meson spectrum in QCD Lattice calculations

Lattice-QCD predictions for the lowest hybrid states

- $0^{++}$: 1.9 GeV
- $1^{-+}$: 1.6 GeV

Hybrid mesons and glueballs mass range:

- 1.4 GeV - 3.0 GeV

This mass range is accessible in photoproduction experiments with a beam energy in the range $5 \text{ GeV} < E_{\gamma} < 12 \text{ GeV}$

Perfectly matched to JLab12 energy!

Meson spectroscopy program in CLAS12

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 many different final states
  - Charged and neutral-rich decay modes
  - \( \gamma p \rightarrow p \ 3\pi \), \( \gamma p \rightarrow p \ \eta \ \pi \), ....

☆ Hybrids with hidden strangeness and strangeonia
  - Intermediate mass of s quarks links long to short distance QCD potential
  - Good resolution and kaon Id required
  - \( \gamma p \rightarrow p \ \phi \ \pi \), \( \gamma p \rightarrow p \ \phi \ \eta \), \( \gamma p \rightarrow p \ 2K \ \pi \), ...

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

Approved by JLab PAC37 with rate A-
Partial Wave Analysis

- Parametrize the cross section in term of partial waves
- Fit to data to extract amplitudes
- A model is needed to parametrize amplitudes:
  - Isobar Model, Dispersion Relations, ...
- Strong interaction between theoreticians and experimentalists to develop the best analysis framework

PWA were successfully performed on CLAS data
(\(\gamma p \rightarrow p \pi^+ \pi^-\), \(\gamma p \rightarrow n \pi^+ \pi^+ \pi^-\), ...) using different models

e.g. first observation of the \(f_0(980)\) in a photoproduction experiment
The Detector

- Determination of $J^{PC}$ of meson states requires Partial Wave Analysis
- Decay and Production of exclusive reactions
- Good acceptance, energy resolution, particle Id

Hall-D - GlueX Detector
- Good hermeticity
- Uniform acceptance
- Limited resolution
- Limited pID

Hall-B - CLAS12 Detector
- Good resolution
- Good pID
- Reasonable hermeticity
- Un-uniform acceptance
Quasi-real photoproduction with CLAS12
(Low $Q^2$ electron scattering)

- Electron scattering at “0” degrees (2.5° - 4.5°)
  low $Q^2$ virtual photon $\leftrightarrow$ 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 $\sim$ 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 5cm $H_2$ ($L=10^{35}$ cm$^{-2}$s$^{-1}$)
- Multiparticle hadronic states detected in CLAS12
  High resolution and excellent PID (kaon identification)

Complementary to Hall-D (GLUEX)
Forward Tagger

Calorimeter + hodoscope + tracker

Electron energy/momentum
Photon energy ($\nu = E - E'$)
Polarization $\varepsilon^{-1} \sim 1 + \nu^2/2EE'$

Veto for photons

Electron angles
$Q^2 = 4EE' \sin^2 \theta/2$
Scattering plane

Rates in the forward tagger

Inelastic electro-production
Elastic radiative tail
Moeller scattering

Signal

Background

Single arm: $R \sim 7$ kHz

Single arm: $R \sim 40$ kHz

Rate in the forward tagger

$L_e \sim 10^{35}$ cm$^{-2}$ s$^{-1}$
$N_\gamma \sim 5 \times 10^8 \gamma$/s

Atomic electron

Single arm: $R \sim 180$ kHz
Forward Tagger

Calorimeter + hodoscope + tracker

Electron energy/momentum
Photon energy ($\nu = E - E'$)
Polarization $\varepsilon^{-1} \approx 1 + \nu^2 / 2EE'$

Veto for photons

Electron angles
$Q^2 = 4 EE' \sin^2 \theta / 2$
Scattering plane

Rates in the forward tagger

Inelastic electro-production
Elastic radiative tail
Moeller scattering

Signal

Background

Atomic electron

FT/CLAS12 coinc: $R \sim 1 \text{ kHz}$

FT/CLAS12 coinc: $R = 0$

$R_{\text{RND}} \sim 1 \text{ kHz}$

$L_e \sim 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$
$(N_\gamma \sim 5 \times 10^8 \gamma / \text{s})$
Forward Tagger

**Calorimeter + hodoscope + tracker**

- **Electron energy/momentum**
  - Photon energy \( (\nu = E - E') \)
  - Polarization \( \epsilon^{-1} \sim 1 + \nu^2/2EE' \)

- **Veto for photons**

- **Electron angles**
  - \( Q^2 = 4EE' \sin^2 \delta/2 \)
  - Scattering plane

**Calorimeter**

- **Specs**
  - Radiation hard
  - Good light yield
  - Energy resolution
  - Time resolution
  - Light read-out (APD/SiPM)

**Homogeneous, fast, dense, inorganic-crystals (PbWO4)**

**CLAS-IC**

**PANDA-EC**
Forward Tagger

Calorimeter + hodoscope + tracker

Electron energy/momentum
  Photon energy ($\nu = E - E'$)
  Polarization $\varepsilon^{-1} \sim 1 + \nu^2/2EE'$

Veto for photons

Electron angles
  $Q^2 = 4 EE' \sin^2 \theta/2$
  Scattering plane

Hodoscope
  Specs
    ✫ Good timing (<ns) for MIPs
    ✫ High segmentation
      (same as the cal or higher)
    ✫ 100% efficient to charged particles

Plastic scintillator tiles with WLS fibres coupled to SiPM

CLAS-HODO
Forward Tagger

Calorimeter + hodoscope + tracker

Electron energy/momentum
Photon energy ($\nu = E - E'$)
Polarization $\varepsilon^{-1} \sim 1 + \nu^2 / 2EE'$

Veto for photons

Electron angles
$Q^2 = 4 EE' \sin^2 \frac{\delta}{2}$
Scattering plane

Tracker

Specs
- 5T solenoidal field
- High pixel density (FW)
- 100-300 $\mu$m resolution
- Integrated in the CLAS12 base equipment

Sustain high rate, moderate resolution, low material budget (Micromegas)

CLAS12-$\mu$M
The Forward Tagger in CLAS12

★ Compatible with standard electron runs

★ Photon detector for leading DVCS experiments
★ Extend the CLAS12 coverage for neutrals at small angles

Photons and electrons can run in parallel!
GEANT4 Simulations
FT (cal+hodo+trk) and W shield in GEMC

Tagged electrons
(E = 0.5 - 4.5 GeV)

☆ Angular resolution (Δφ~2.8°, Δθ/θ~1.6%)
☆ Tracking and calorimeter efficiency
☆ Clusters reconstruction in calorimeter

EM background

☆ Effect on track-finding algorithm
☆ Effect on drift chamber occupancy
☆ Rates and radiation dose in the calorimeter

R.DeVita, D.Glazier, S.Procurer
GEANT4 Simulations

Expected energy resolution

R + 30 MeV/crystal thr

Resolution (R) + 10 MeV/crystal thr
- light yield=120 photons/MeV (0.3% of NaI)
- 5x5 mm² APDs
- APD gain=250
- APD stability: $DV=30 \text{ mV and } DT=0.1\text{C}$
- preamp input noise=4500 electrons

IR + 10 MeV/crystal thr

Intrinsic resolution (IR)

Resolution

% virtual photon energy

$\chi^2 / \text{ndf} = 88.85 / 46$
p1 = $1.782 \pm 0.060$
p2 = $2.234 \pm 0.057$
p3 = $0.6429 \pm 0.0468$
GEANT4 Simulations

Calorimeter geometry optimization

Intrinsic resolution
%
crystal length

Intrinsic resolution
%
surrounding materials

Paris-11
Forward photon tagging facility
M.Battaglieri INFN-GE
Forward Tagger with Micromegas?

Project to equip the FMT with central pixels for small angle e- detection

- add ~ 6k channels to the FMT (electronics?)
- add 2-4 MM layers in front of calo

Very large background due to Moeller

S. Procurer

Track finding eff > 95% in pFMT

M. Battaglieri INFN-GE
R&D on crystals and light readout

*D.Watts, D.Glazier*

**First**

spectrophotometer
tests of PbW0
crystals

![Chinese PbWO4 sample - Transmittance perp to crystal 5 cm from one end](image)

Edinburgh test of Chinese crystal. Room temperature measurements of transmittance through crystal. Tested ~5 cm from one end of crystal.

**Different amplifiers and photosensors (APD/SiPM) tested with Co60**

*SiPM linearity*

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Photo-sensor</th>
<th>Amplifier</th>
<th>Sigma/E</th>
<th>Noise</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>LYSO</td>
<td>APD Large Area</td>
<td>Genoa-Made</td>
<td>x</td>
<td>4 mV</td>
<td>Room temperature</td>
</tr>
<tr>
<td>LYSO</td>
<td>APD Large Area</td>
<td>JLab-made</td>
<td>0.071</td>
<td>14 mV</td>
<td>17.4</td>
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<tr>
<td>LYSO</td>
<td>APD Large Area</td>
<td>JLab-made</td>
<td>0.061</td>
<td>12.8 mV</td>
<td>-17.9</td>
</tr>
<tr>
<td>LYSO</td>
<td>SiPM Matrix 2x2 (14400 pixels each)</td>
<td>JLab-made, modified</td>
<td>0.1373</td>
<td>2.9 mV</td>
<td>15.4</td>
</tr>
</tbody>
</table>

Hamamtsu LAAPD 10x10 mm2

Hamamtsu SiPM 10x10 mm2 2x2 ch 3x3 mm2
**FT Mechanical structure**

- Realistic mechanical designs
- Realistic thermal simulations
- First meeting with JLab engineers

Alignment & Positioning

A. Bersani, R. DeVita, F. Parodi
The Forward Tagger in CLAS12 CAD

A. Bersani
Physics channel simulations

- Evaluate CLAS12 acceptance for multiparticle final states
- Define resolution for exclusive channel selection (missing mass technique) and mass reconstruction

Benchmark channels

- $\gamma p \rightarrow n \pi^+ \pi^+ \pi^-$
- $\gamma p \rightarrow p \eta \varphi$
- $\gamma p \rightarrow n \eta \pi^+$
- $\gamma p \rightarrow p K^+ K^- \pi^0$
- $\gamma p \rightarrow n \text{Res} \rightarrow n \pi^+ \pi^+ \pi^-$

Acceptance (all 3 $\pi$ det)

Resonance parameters

- $M=1.4$ GeV, $\Gamma=150$ MeV
- $M=1.7$ GeV, $\Gamma=150$ MeV
- $M=2.0$ GeV, $\Gamma=150$ MeV

- Extended kinematic coverage
- Flat acceptance in the meson rest frame
Partial Wave Analysis in CLAS12

D.Glazier, C.Salgado, D.Weygand

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

The process is described as sum of 8 isobar channels:
- \( a_2 \rightarrow \rho \pi \) (D-wave)
- \( a_1 \rightarrow \rho \pi \) (S-wave)
- \( a_1 \rightarrow \rho \pi \) (D-wave)
- \( \pi_2 \rightarrow \rho \pi \) (P-wave)
- \( \pi_2 \rightarrow \rho \pi \) (F-wave)
- \( \pi_2 \rightarrow f_2 \pi \) (S-wave)
- \( \pi_2 \rightarrow f_2 \pi \) (D-wave)
- \( \pi_1 \rightarrow \rho \pi \) (P-wave) (exotic)

- Amplitudes calculated by A.Szczepaniak and P.Guo
- CLAS12 acceptance projected and fitted

- PWA is stable against CLAS12 acceptance/resolution distortion

PWA in CLAS12 is feasible!

Black = generated blue/red = fit \( t=0.2 \text{ GeV}^2 \) (0.5 GeV²)
Expected results

Production

Cross sections

\[ \sigma(\gamma p \rightarrow p \, 3\pi) \sim 10 \, \mu b \]
\[ \sigma(\gamma p \rightarrow p \, \eta \, \pi) \sim 0.2 \, \mu b \]
\[ \sigma(\gamma p \rightarrow p \, K \, K \, \pi) \sim 10 \, \text{nb} \]
\[ \sigma(\gamma p \rightarrow p \, \phi \, \eta) \sim 10 \, \text{nb} \]

Assuming exotic meson production

\[ \sim 1\% \]

Yield/Mass bin to run PWA

\[ \sim 5000 \, \text{ev} \]

80 days of production beam time

Can be scheduled in parallel to already approved electron runs

Commissioning and calibration

★ 15d FT commissioning
★ 20d+4d low luminosity \((L_e \sim 5 \times 10^{33} \, \text{cm}^{-2} \, \text{s}^{-1})\) & minimum bias trigger (2-prongs)

Expected yield 20d run

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

Expected yield 80d run

\[ \gamma p \rightarrow p \, (K^-) \, K^+ \, \pi^0 \]

Red = half-field

Blue = full-field

Red = half-field

Blue = full-field
Exotics and strangeness-rich mesons can be studied in the Hall-B with the CLAS12 detector

Low $Q^2$ electron scattering is a complementary technique to the Hall-D coherent Bremsstrahlung

New equipment: Forward Tagger (calorimeter+hodoscope+tracker) compatible with standard operation of CLAS12

Excellent CLAS12 resolution and particle Id

Complete PWA feasible in CLAS12

Dedicated detectors and high intensity photon beams at JLab-12 are under construction, ready to run in a near future!