GLUEX and Hall-D

Yves Van Haarlem
for the GLUEX collaboration

Carnegie Mellon

Users Group Workshop and Annual Meeting, June 9, 2009
Confinement

Quantum Chromodynamics
- Gluons have color-charge
  → are self interacting
- Gives rise to flux tubes
  (Bernard et al. - 2004)
- \( V(r) = \kappa r \)
- Non-perturbative
**Confinement**

- **Quantum Chromodynamics**
  - Gluons have color-charge → are self-interacting
  - Gives rise to flux tubes (Bernard *et al.* - 2004)
  - $V(r) = \kappa r$
  - Non-perturbative

- **Mesons**
  - 2 quarks ($q\bar{q}$)
  - Studied/mapped in spectroscopy
  - Characterized by $J^{PC}$ quantum numbers
  - Some $J^{PC}$ are not allowed ($q\bar{q}$) (e.g. $0^{+-}$):
    → Exotic mesons

0$^{+-}$: $\pi^+$
1$^{--}$: $\rho^+$
Can the glue be excited?

- Mesons with excited flux tube
  - Hybrids: $L$ in flux tube
    - $J^{PC} = 1^{+-}$ and $1^{--}$
  - About 1 GeV/$c^2$ above ground state meson spectrum
  - Exotic quantum numbers possible

Lattice calculations predict:

- $1^{+-}$: $\sim 1.9$ GeV/$c^2$ (lightest nonet)
- $2^{++}$: $\sim 2.1$ GeV/$c^2$
- $0^{+-}$: $\sim 2.3$ GeV/$c^2$

→ Exotic quantum numbers!

GlueX wants to map out the hybrid mesons

Measurement of the excited QCD potential
Can the glue be excited?

- Mesons with excited flux tube
  - Hybrids: L in flux tube
    - $J^{PC} = 1^{+-}$ and $1^{--}$
  - About 1 GeV/$c^2$ above ground state meson spectrum
  - Exotic quantum numbers possible

- Lattice calculations predict:
  - $1^{--}: \sim 1.9$ GeV/$c^2$ (lightest nonet)
  - $2^{+-}: \sim 2.1$ GeV/$c^2$
  - $0^{+-}: \sim 2.3$ GeV/$c^2$
  → Exotic quantum numbers!

...
Can the glue be excited?

- Mesons with excited flux tube
  - Hybrids: L in flux tube
    - $J^{PC} = 1^{+-}$ and $1^{-+}$
  - About 1 GeV/$c^2$ above ground state meson spectrum
  - Exotic quantum numbers possible

Lattice calculations predict:


- $1^{-+}$: $\sim 1.9$ GeV/$c^2$ (lightest nonet)
- $2^{+-}$: $\sim 2.1$ GeV/$c^2$
- $0^{+-}$: $\sim 2.3$ GeV/$c^2$

→ Exotic quantum numbers!

→ GlueX wants to map out the hybrid mesons

Measurement of the excited QCD potential
\[ \pi/\gamma \text{ BEAM?} \]

**π beam**

- \( \pi \) with excited flux tube:
  - \( m=1, S=0, L=0, J=1 \rightarrow 1^{++} 1^{--} \)
- Quark spin flip \( \rightarrow \) exotic hybrids

**BUT** \( \sigma_{\text{exotic-meson}} \) reduced \( ( \ll \sigma_{\text{meson}} ) \)

- A lot of data but little evidence for hybrids
**π/γ BEAM?**

**π beam**
- π with excited flux tube:
  - $m=1$, $S=0$, $L=0$, $J=1 \rightarrow 1^{++}$ $1^{--}$
- Quark spin flip $\rightarrow$ exotic hybrids
  - **BUT** $\sigma_{exotic-meson}$ reduced ($\ll \sigma_{meson}$)
- A lot of data but little evidence for hybrids

**γ beam**
- $q\bar{q}$ with excited flux tube:
  - $m=1$, $S=1$, $L=0$, $J=0,1,2$
    $\rightarrow 0^{-+}$ $0^{++}$ $1^{--}$ $1^{++}$ $2^{-+}$ $2^{++}$
  - Exotic hybrids!
- $\sigma_{exotic-meson} \approx \sigma_{meson}$
- Almost no data available
- Linear polarized $\gamma \rightarrow$ parity measurement
Hybrid decays in the fluxtube model

One decay meson gets $L_{\text{flux}}$:
→ $L=0$ meson + $L=1$ meson (most models)

Examples of final states:
- $\eta_1 \rightarrow a_1^+ \pi^- \rightarrow \ldots \rightarrow \pi^+ \pi^- \pi^+ \pi^-$
- $h_0 \rightarrow b_1^0 \pi^0 \rightarrow \ldots \rightarrow \pi^+ \pi^- \gamma \gamma \gamma \gamma \gamma$
- $h'_2 \rightarrow K_1^+ K^- \rightarrow \ldots \rightarrow \pi^+ \pi^- K^+ K^-$

GlueX needs to detect:
- Charged particles
- Multiple $\gamma$s
  - 70% involved at least one $\pi^0$
  - 50% more than one $\pi^0$
- Strange particles

<table>
<thead>
<tr>
<th>Exotic Meson</th>
<th>$J^{PC}$</th>
<th>$I$</th>
<th>$G$</th>
<th>Possible Modes</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b_0$</td>
<td>0$^{+-}$</td>
<td>1</td>
<td>+</td>
<td>$b_1 \pi$</td>
</tr>
<tr>
<td>$h_0$</td>
<td>0$^{+-}$</td>
<td>0</td>
<td>−</td>
<td>$b_1 \pi$</td>
</tr>
<tr>
<td>$\pi_1$</td>
<td>1$^{-+}$</td>
<td>1</td>
<td>−</td>
<td>$\rho \pi$, $b_1 \pi$</td>
</tr>
<tr>
<td>$\eta_1$</td>
<td>1$^{-+}$</td>
<td>0</td>
<td>+</td>
<td>$a_2 \pi$</td>
</tr>
<tr>
<td>$b_2$</td>
<td>2$^{+-}$</td>
<td>1</td>
<td>+</td>
<td>$a_2 \pi$</td>
</tr>
<tr>
<td>$h_2$</td>
<td>2$^{+-}$</td>
<td>0</td>
<td>−</td>
<td>$\rho \pi$, $b_1 \pi$</td>
</tr>
</tbody>
</table>
Requirements for hybrid spectroscopy

- **γ - beam** ($\sigma_{exotic-meson}$)
  - Linearly polarized (parity)
  - High enough in energy (to produce hybrids)
  - High luminosity

- **Detector**
  - Large & uniform acceptance
  - Good calorimetry (multiple $\gamma$s)
  - Good momentum resolution
  - Charged particle ID
  - Handle high luminosity
Requirements for hybrid spectroscopy

γ - beam ($\sigma_{\text{exotic-meson}}$)
- Linearly polarized (parity)
- High enough in energy (to produce hybrids)
- High luminosity

Detector
- Large & uniform acceptance
- Good calorimetry (multiple $\gamma$s)
- Good momentum resolution
- Charged particle ID
- Handle high luminosity

Hall-D integrated in 12 GeV upgrade of JLab
Ground Breaking Ceremony - Apr. 14, 2009
(Construction started in May 2009)
- $e^-(12\ \text{GeV}/c)$ on $20\ \mu m$ diamond
- Coherent bremsstrahlung - $\gamma$-beam
- $8.4-9\ \text{GeV} \ \vec{\gamma}_s$ (tagged)
- $10^8 \ \vec{\gamma}/s$ on p target (collimated)
- Solenoid based detector
**LINEARLY POLARIZED \( \gamma \)-BEAM**

- 10^8 \( \gamma / \text{s} \) on target:
  - 12 GeV/c e-momentum
  - 2.2 \( \mu \text{A} \) e-beam
  - 20 \( \mu \text{m} \) diamond crystal
  - 75 m diamond-collimator
  - Active collimator aperture: 3.5 mm
- Peak linear polarization: 40%
- Electron pair spectrometer
  - Measures post-collimated \( \gamma \)-beam spectrum
  - Essential for determination of the beam polarization
TAGGER

- 1.5 T dipole, 6 m long, 30 mm pole gap
- Deflects electrons ($13.4° = 12$ GeV)
- 190 Hodoscopes: scintillator + PMTs (12 m long)
  $\rightarrow$ 3 - 11.7 GeV
- Microscope: 124 scintillating fibers (movable) + SiPMs
  $\rightarrow$ 8.3 - 9.1 GeV ± 8 MeV
Spectrometer

- Liquid H target - 30 cm long
- Solenoid: 2.24 T
- Tracking (inside solenoid):
  - Start counter
  - Central Drift Chamber (CDC)
  - Forward Drift Chamber (FDC)
- Calorimetry
  - Barrel Calorimeter (BCAL)
  - Forward Calorimeter (FCAL)
- Time-of-flight wall (ToF)
- Custom read-out & trigger
Which tagged $e^-$ belongs to $\gamma$?

- Together with tagger
- 40 scintillators (+PMTs or SiPMs)
- $r = 8 \text{ cm}$
- 50 cm Straight $+$ 10 cm bended (35°)
- Only used in initial phase (lower rate)
- Energy and timing measurements
Central Drift Chamber

- 3500 Straws ($r=8\ mm$): 28 layers
- 6 - 150° optimal angular coverage
- Resolution: $\sigma_{r\phi} = 150\ \mu m$, $\sigma_z = 1.5\ mm$
- $\frac{dE}{dx}$ for $\pi$/proton ID ($p < 450\ MeV/c$)
Forward Drift Chamber

- 4 packages: ground - cathode(75°) - wire(0°) - spacer - cathode plane(-75°)
  → suppression of ambiguities
- 1 - 30° angular coverage
- $\sigma_{xy} = 200 \ \mu m$
**Barrel Calorimeter**

  - 28 segments
  - inner segment → SiPMs
  - Outer segment → PMTs
- \( \sigma_E/E \text{ (\%)} = 5.54/\sqrt{E} + 1.6 \) (testbeam)
- Charged particle PID (ToF: TDC)
**Barrel Calorimeter**

  - 28 segments
  - inner segment → SiPMs
  - Outer segment → PMTs
- \( \sigma_E/E \) (\%) = 5.54/\( \sqrt{E} \) + 1.6 (testbeam)
- Charged particle PID (ToF: 62 ps TDC)
**Time-of-Flight Scintillator Wall**

- 5.5 meters downstream the target
- 2 layers of 42 scintillator bars/each
- Time resolution/plane: 80 ps

![Diagram of scintillator wall with dimensions and features]
Time-of-Flight Scintillator Wall

- 5.5 m downstream the target
- 2 layers of 42 scintillator bars/each
- Time resolution/plane: 80 ps
- Good charged PID up to 2 GeV/c

Graph:

TOF distance 550 cm
solid 3σ p-res. 4%
dot 3σ TDC 60ps + TOF 80ps

Yves Van Haarlem (CMU)
**Forward Calorimeter**

- 5.6 m away from target
- 2800 lead glass blocks (used before in E852 and RadPhi)
- Stacked in circular shape: 2.4 m diameter
- $\sigma/E \, (\%) = \frac{5.6}{\sqrt{E}} + 2.0$
- $\sigma_{xy} \approx 0.64 \, cm/\sqrt{E}$
**Forward Calorimeter**

As used in E852 at BNL
**Trigger**

3 \cdot 10^8 \text{ tagged } \gamma \text{s/s:}

- EM background
  - Pair production
  - Compton scattering
  - Dominant background
- Hadronic photoproduction
  - 360 kHz
3 \cdot 10^8$ tagged $\gamma$s/s:
- **EM background**
  - Pair production
  - Compton scattering
  - Dominant background
- **Hadronic photoproduction**
  - 360 kHz

**Level-1 trigger**: $\to \sim 200$ kHz
- Studied with Geant simulation
  - hadronic + em (pile up)
- Energy deposition in FCAL and BCAL
- $\#$ hits in Tagger, ToF wall, and start-counter
- Trigger efficiency for exotic decays: $>98$

![Graph showing photon beam energy and events accepted by Level-1 trigger](image)
3 \cdot 10^8 \text{ tagged } \gamma/s/s:
- EM background
  - Pair production
  - Compton scattering
  - Dominant background
- Hadronic photoproduction
  - 360 kHz

- **Level-1 trigger**: $\rightarrow \sim 200$ kHz
  - Studied with Geant simulation
    - hadronic + em (pile up)
  - Energy deposition in FCAL and BCAL
  - # hits in Tagger, ToF wall, and start-counter
  - Trigger efficiency for exotic decays: $>98\%$

- **Level-3 trigger**: $\rightarrow \sim 20$ kHz
  - Computer farm
  - Only for high lumi runs

![Photon beam energy](image1)

![N_{TRIG}/N_{TOTAL}](image2)
STATUS

- (DOE) CD-3 granted in September 2008
- HALL-D civil construction started May 2009
- BCal is being built
- Procurement for other detectors is in progress
- Beam on target: 2014
Physics potentials with Hall-D

Photon-hadron physics workshop (PHP) (March 2008)

⇒ http://conferences.jlab.org/php2008/index.html

- Primakoff effect
  - Good forward calorimetry needed
- Photo-production on nuclear targets
  - Medium effects on hadron production
- Charm photo-production (near threshold)
- Baryon ($\Xi^-$) spectroscopy
  - Good PID needed
- Inverse Virtual Compton Scattering (iVCS)
- Your idea

New collaborators are welcome!

Yves Van Haarlem (CMU)
Physics potentials with Hall-D

Photon-hadron physics workshop (PHP) (March 2008)

⇒ http://conferences.jlab.org/php2008/index.html

- Primakoff effect
  - Good forward calorimetry needed
- Photo-production on nuclear targets
  - Medium effects on hadron production
- Charm photo-production (near threshold)
- Baryon (Ξ−) spectroscopy
  - Good PID needed
- Inverse Virtual Compton Scattering (iVCS)
- Your idea

New collaborators are welcome!
The GlueX collaboration

- Carnegie Mellon (CDC)
- Catholic University
- Christopher Newport
- Florida International (start-counter)
- Florida State (ToF wall)
- Glasgow ($\gamma$-beam)
- Indiana University (FCal)
- IUCF (CDC, FDC)

- Jefferson Lab (CDC, FDC, BCal, $\gamma$-beam)
- Langzou University
- University of Connecticut ($\gamma$-beam)
- University of Alberta (BCal)
- University of Athens (BCal)
- University of Pennsylvania (CDC, FDC)
- University of Regina (BCal)
- Yerevan ($\gamma$-beam)
The GlueX collaboration

- Will map out the hybrid mesons ($< 2.5 \text{ GeV/c}$) and will do other interesting physics
  - High intensity $9 \text{ GeV}$ linear polarized photons
  - Large acceptance spectrometer
    - In the new experimental Hall-D at JLab
- Procurement and construction in progress
- We welcome new participants