Physics Program at Jefferson Lab Hall-D

Yi Qiang
Jefferson Lab

for the GlueX Collaboration

July 3, 2013
Jefferson Lab 12 GeV Upgrade

- New experimental Hall-D
- Enhanced capabilities in existing Halls
- Max beam energy: 12 GeV to Hall-D, 11 GeV to Hall-A/B/C
GlueX Program
Gluon Interactions in QCD

- QCD has interesting properties
  - Confinement: force is strong at large distances
  - Gluon-gluon interactions

- How do these properties exhibit themselves in experimental data?
  - What role do gluons play in the structure of matter?
  - Does QCD predict experimentally observable gluonic excitations?
  - Can we observe evidence for gluonic degrees of freedom in the spectrum of meson states?
Hall-D’s Flagship: GlueX Program

- Conventional meson has quantum numbers determined only by constituent quarks:
  \[ S = S_1 + S_2 \]
  \[ J = L + S \]
  \[ P = (-1)^{L+1} \]
  \[ C = (-1)^{L+S} \]
  Possible \( J^{PC} \) s: 0\(^{-+}\), 0\(^{++}\), 1\(^{++}\), 1\(^{+-}\), 2\(^{+-}\), 2\(^{++}\)

- Gluon excitation introduces additional degrees of freedom
- Hybrid meson has excited gluons as constituent particles
- Multiplets of states expected
- More \( J^{PC} \) combinations allowed: 0\(^{-+}\), 0\(^{++}\), 0\(^{+-}\), 1\(^{++}\), 1\(^{+-}\), 1\(^+-\), 2\(^{-+}\), 2\(^{++}\), 2\(^{+-}\)
- Unique signature: exotic states
Lattice QCD Calculations

Dudek PRD 82 (2010) 034508
Dudek PRD 83 (2011) 111502
Dudek PRD 84 (2011) 074023

$m_\pi = 396$ MeV

isoscalar
isosvector
YM glueball

hybrids

Thomas Jefferson National Accelerator Facility
Yi Qiang - Physics Program at JLab Hall-D - 5th Hadron Workshop, China
Lattice QCD predicts quark flavor mixing angles for isoscalar hybrids.

Experimentally, internal quark structure can be inferred by comparing decay modes, for example:

\[
\frac{\mathcal{B}(f_2'(1525) \rightarrow \pi\pi)}{\mathcal{B}(f_2'(1525) \rightarrow KK)} \approx 0.009
\]

\[
\frac{\mathcal{B}(f_2(1270) \rightarrow KK)}{\mathcal{B}(f_2(1270) \rightarrow \pi\pi)} \approx 0.05
\]

(measured values)

By studying many decay modes, GlueX may be able to qualitatively validate LQCD predictions.
**Experimental Evidence for $1^{-+}$ Exotic Hybrids**

### $\pi_1(1400)$

$I^G(J^{PC}) = 1^-(1-+)$

See also the mini-review under non-$q\bar{q}$ candidates in PDG 06, Journal of Physics, G 33 1 (2006).

### $\pi_1(1600)$

$I^G(J^{PC}) = 1^-(1-+)$

### $\pi_1(1600)$ MASS

<table>
<thead>
<tr>
<th>VALUE (MeV)</th>
<th>EVTS</th>
<th>DOCUMENT ID</th>
<th>TECN</th>
<th>CHG</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1354 ± 25</td>
<td>OUR AVERAGE</td>
<td>Error includes scale factor of 1.8. See the ideogram below.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### $\pi_1(2015)$

$I^G(J^{PC}) = 1^-(1-+)$

<table>
<thead>
<tr>
<th>MASS (MeV)</th>
<th>WIDTH (MeV)</th>
<th>EVTS</th>
<th>DOCUMENT ID</th>
<th>TECN</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014 ± 20 ± 16</td>
<td>230 ± 32 ± 73</td>
<td>145k</td>
<td>LU</td>
<td>05</td>
<td>B852 $18 \pi^- p \rightarrow \omega \pi^- \pi^0 p$</td>
</tr>
<tr>
<td>2001 ± 30 ± 92</td>
<td>333 ± 52 ± 49</td>
<td>69k</td>
<td>KUHN</td>
<td>04</td>
<td>B852 $18 \pi^- p \rightarrow \eta \pi^+ \pi^- \pi^- p$</td>
</tr>
</tbody>
</table>

**Unlikely hybrid**

**Dynamical origin, FSI?**

**May be hybrid**

**Challenge in $3\pi$ from $\pi_2$ background**

**Cleaner $\eta'\pi$ signal**

**Among “further states”**

**Needs confirmation**
Photo-production of Exotic Hybrids

- Photo-production
  - The expectation from the flux tube model is that hybrids will be produced at a rate comparable to normal mesons.
  - Photons have spin-1, allowing easier production of exotics compared to pion beams where a spin flip must occur.

- Photon Polarization
  - Polarized photon beam helps determine production mechanism.
  - Linear polarization puts additional constraints on particle quantum numbers through partial wave analysis (PWA).
### Key Decay Modes of Exotics

#### Experiment requirements

- Ability to identify multiparticle final states: charged particles and photons
- High statistics and hermetic detection system
- $K/\pi$ separation is helpful to identify whole hybrid family

#### Table

<table>
<thead>
<tr>
<th>Approximate Mass (MeV)</th>
<th>$j^PC$</th>
<th>Total Width (MeV)</th>
<th>Relevant Decays</th>
<th>Final States</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi_1$</td>
<td>$1^{--}$</td>
<td>80 – 170</td>
<td>$b_1 \pi^+, \rho \pi^+, f_1 \pi^+, \eta_1 \pi^+$, $\eta' \pi^+$</td>
<td>$\omega \pi^+, 3\pi^+, 5\pi, \eta 3\pi^+, \eta' \pi^+$</td>
</tr>
<tr>
<td>$\eta_1$</td>
<td>$1^{--}$</td>
<td>60 – 160</td>
<td>$a_1 \pi, f_1 \eta^+, \pi(1300)\pi$</td>
<td>$4\pi, \eta 4\pi, \eta \pi \pi$</td>
</tr>
<tr>
<td>$\eta_1'$</td>
<td>$1^{--}$</td>
<td>100 – 220</td>
<td>$K_1(1400)K^+, K_1(1270)K^+, K^*K^+$</td>
<td>$KK\pi\pi^+, KK\pi^+, KK\omega^+$</td>
</tr>
<tr>
<td>$b_0$</td>
<td>$0^{+-}$</td>
<td>250 – 430</td>
<td>$\pi(1300)\pi, h_1 \pi$</td>
<td>$4\pi$</td>
</tr>
<tr>
<td>$h_0$</td>
<td>$0^{+-}$</td>
<td>60 – 260</td>
<td>$b_1 \pi, h_1 \eta, K(1460)K$</td>
<td>$\omega \pi\pi^+, \eta 3\pi, KK\pi\pi$</td>
</tr>
<tr>
<td>$h_0'$</td>
<td>$0^{+-}$</td>
<td>260 – 490</td>
<td>$K(1460)K, K_1(1270)K, h_1 \eta$</td>
<td>$KK\pi\pi^+, \eta 3\pi$</td>
</tr>
<tr>
<td>$b_2$</td>
<td>$2^{+-}$</td>
<td>10</td>
<td>$a_2 \pi, a_1 \pi, h_1 \pi$</td>
<td>$4\pi, \eta \pi \pi^+$</td>
</tr>
<tr>
<td>$h_2$</td>
<td>$2^{+-}$</td>
<td>10</td>
<td>$b_1 \pi, \rho \pi$</td>
<td>$\omega \pi\pi^+, 3\pi^+$</td>
</tr>
<tr>
<td>$h_2'$</td>
<td>$2^{+-}$</td>
<td>10 – 20</td>
<td>$K_1(1400)K, K_1(1270)K, K_2^*K$</td>
<td>$KK\pi\pi^+, KK\pi^+$</td>
</tr>
</tbody>
</table>

† experimentally promising: few particles or narrow isobars

High priority exotic search channels in initial running
GlueX Experimental Setup

- Part of 12 GeV upgrade to JLab
- High luminosity linearly polarized photon beam
- Liquid Hydrogen target
- Hermetic detection of charged and neutral particles in solenoid magnet

Rating: A
Total beam time: 320 days
Photon Beam and Tagger

- 12 GeV electron Beam
- Coherent Peak @ 9 GeV
- $M_X$ up to 2.8 GeV
- 20 $\mu$m diamond radiator
- Polarization: 40%

- Diamond Radiator
  
  $e^- Z \rightarrow \gamma e^- Z$

- Electron Beam Dump

- Collimator
  select $\Theta < 25 \mu$r polarized photons

- GlueX Spectrometer

- Hall-D

- Tagger Magnet

- Initial photon flux: $10^7 \gamma$/s on Target ($\Delta E\gamma = 8.4 - 9$ GeV)
- Design expandable to $10^8 \gamma$/s
Solenoid: Testing in Progress

- Used for LASS at SLAC, for MEGA at Los Alamos, refurbished for Hall-D
- Bore inner diameter 1.85 m, length 4 m, $B_{\text{MAX}} 2.2 \text{ T @ 1500 A}$
Barrel Calorimeter (BCAL)

- SciFi calorimeter modules
  - Fabricated by Univ. of Regina
  - 48 Modules (φ sectors)
  - 191 layers
  - Pb/Scint./glue = 37/49/14%

- Photon readout
  - Readout from both sides
  - 3840 Silicon Photo Multiplier (SiPM) arrays from Hamamatsu: 1.2×1.2 cm²
  - Immune to magnetic fields
  - Temperature control: 5°C
Forward Calorimeter (FCAL)

- **Lead Glass Calorimeter**
  - Fabricated at Indiana University
  - 2800 lead glass F8-00 blocks $4 \times 4 \times 45$ cm$^3$
  - FEU84-3 PMTs and Cockroft-Walton bases

- **Prototype test at Hall-B, 2012**
  - $\delta E/E = 20\%$ with 100 MeV electrons, as expected
Charged Particle Tracking

- **Forward Drift Chamber (FDC)**
  - Built and tested at JLab
  - Round planar chambers with cathode strips (U/V) and anode wires readout
  - 4 packages, 6 readout planes per package
  - Resolution: $\sigma = 150 \, \mu m$

- **Central Drift Chamber (CDC)**
  - Fabricated at Carnegie Mellon University
  - Straw chamber: 3500 straw tubes
  - Resolution: $\sigma_{r\phi} = 150 \, \mu m$, $\sigma_Z = 1.5 \, mm$
  - $dE/dx$ for proton identification (<450 MeV)
  - Fully wired, being tested
Particle ID and Timing

- **Start Counter (SC)**
  - Being fabricated at Florida International University
  - Thin scintillator to tag accelerator beam bunch
  - Readout by SiPMs

- **Forward TOF (TOF)**
  - Being fabricated at Florida State University
  - Two scintillator planes: 70 ps resolution, $4\sigma$ $K/\pi$ separation up to 2 GeV
Electronics and Trigger

- Fully pipelined payload modules (VME64-VXS)
  - F1-TDC (60 ps, 32 ch. or 115 ps 48 ch.)
  - 125 MHz flash ADC (12 bit, 72 ch.)
  - 250 MHz flash ADC (12 bit, 16 ch.)

- Versatile trigger setup on FPGAs
  - Energy sum, pattern match or combination every 4 ns
  - Initial L1 trigger: simple algorithm on total energy sum
  - L3-farm: reduce L1 trigger rate by a factor of 10

- Trigger/Data Rate
  - 200 kHz, 3 GB/s readout from front end (10^8γ/s)
  - 300 MB/s to tape
Reconstruction and Analysis

- Reconstruction
  - Multi-threaded framework: JANA
  - Working libraries for all sub-systems, improvement ongoing

- Particle identification
  - Kinematic fitting
  - Boosted decision tree

- PWA analysis
  - AmpTool: flexible, take advantages from GPUs

- Data challenges
  - Finished first round, 5.6 B events (30 days of initial running) generated and analyzed
  - Successfully utilized Open Science Grid (OSC)
## Roadmap of GlueX Program

<table>
<thead>
<tr>
<th></th>
<th>Low-intensity</th>
<th>High-intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Phase I</td>
<td>Phase II</td>
</tr>
<tr>
<td>Duration (PAC days)</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Expected Date</td>
<td>2015</td>
<td>2016</td>
</tr>
<tr>
<td>Electron Energy (GeV)</td>
<td>&lt;10</td>
<td>11</td>
</tr>
<tr>
<td>Beam Current (nA)</td>
<td>50 – 200</td>
<td>220</td>
</tr>
<tr>
<td>Photon Flux 8.4-9 GeV (γ/s)</td>
<td>10⁶</td>
<td>10⁷</td>
</tr>
<tr>
<td>Max Beam Emittance (mm-μr)</td>
<td>50</td>
<td>20</td>
</tr>
<tr>
<td>Level-1 Trigger Rate (kHz)</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>Level-3 Farm</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Raw Data Volume (TB)</td>
<td>60</td>
<td>600</td>
</tr>
</tbody>
</table>

- **Initial “low-intensity” runs will provide incredible statistics in some channels**
  - 3×10⁸ events: \( \gamma p \rightarrow \pi^+ \pi^+ \pi^- n \)
  - 5×10⁶ events: \( \gamma p \rightarrow \omega \pi^+ \pi^- p \)
  - 10⁵ - 10⁶ events: \( \gamma p \rightarrow \eta' \pi^+ n \)

- **Approved high-intensity running Phase IV: more decay channels, kaons, cascades**
Other Approved Experiments
**η Radiative Decay Width**

- Measure $\Gamma(\eta \rightarrow \gamma\gamma)$ through Primakoff process
  - Precision tests of Chiral symmetry in QCD
  - Potentially solve collider/Primakoff discrepancy
  - Significantly improve $(\eta - \eta')$ mixing angle measurement

- **Experimental Setup**
  - GlueX detector + LH2/LHe target
  - Addition Calorimeter for cross-section calibration

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[Graph showing cross-section vs. η production angle with $E_{\text{beam}} = 11$ GeV and $\gamma + ^4\text{He} \rightarrow \eta + ^4\text{He}$]

Rating: A⁻  Beam time: 79 days  
Spokespersons: Liping Gan (UNCW), Ashot Gasparian (NCAT)
Charged Pion Polarizability

- **Pion Polarizability**
  - Important test of low-energy QCD unresolved by experiment
  - Predicted value directly from $L_{QCD}(p^4)$, NLO corrections are small

- **Experimental Setup**
  - Primakoff process, near threshold region
  - GlueX Spectrometer + $^{112}$Sn target + muon detector
  - 10% measurement, similar precision to the best theory prediction

Rating: A−, Beam time: 25 days
Spokespersons: David Lawrence (JLab), Rory Miskimen (UMass), Elton Smith (JLab)
Future Plan and Summary
Opportunities and Future Projects

- Tasks need attention
  - BCAL photon reconstruction
  - Detector commissioning and calibration
  - Data analysis: PID and PWA

- Plans for detector upgrades
  - PID upgrade for kaon identification: requirements and options being evaluated – threshold Cherenkov counter, DIRC and RICH
  - Fine granularity forward calorimetry: better energy resolution and $\pi^0$ PID

- Physics under discussion
  - Well developed: Rare eta decay
  - Early stage: charm photoproduction, time-like Compton scattering
  - New ideas are welcome: [http://www.jlab.org/exp_prog/PACpage/](http://www.jlab.org/exp_prog/PACpage/)

- Contacts
  - Yi Qiang ([yqiang@jlab.org](mailto:yqiang@jlab.org))
  - Hall-D leader: Eugene Chudakov ([gen@jlab.org](mailto:gen@jlab.org))
  - GlueX spokesperson: Curtis Meyer ([cmeyer@ernest.phys.cmu.edu](mailto:cmeyer@ernest.phys.cmu.edu))
  - GlueX wiki: [https://halldweb1.jlab.org/wiki](https://halldweb1.jlab.org/wiki)
Summary

- **GlueX: search for exotic mesons**
  - GlueX will study the spectrum of mesons with a polarized photon beam up to 2.8 GeV with sensitivities of a few percent of the total cross section
  - Unique study of QCD in gluonic degrees of freedom

- **Other approved experiments**
  - Radiative decays of $\eta \rightarrow \gamma\gamma$
  - Charged pion polarizability
  - Study of Cascade baryons

- **12 GeV schedule**
  - Hall-D detectors are 80% complete, installation in progress
  - Accelerator commissioning is planned for Jan. 2014
  - Hall-D detector commissioning starts in late 2014
  - GlueX phase I data taking starts in 2015
BACKUP SLIDES
### GlueX Detector Design Parameters

<table>
<thead>
<tr>
<th>Capability</th>
<th>Quantity</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Charged particles</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coverage</td>
<td></td>
<td>$1^\circ &lt; \theta &lt; 160^\circ$</td>
</tr>
<tr>
<td>Momentum Resolution (5° – 140°)</td>
<td>$\sigma_p/p = 1 – 3%$</td>
<td></td>
</tr>
<tr>
<td>Position resolution</td>
<td>$\sigma \sim 150 – 200 , \mu m$</td>
<td></td>
</tr>
<tr>
<td>CDC $dE/dx$ measurements</td>
<td>$20^\circ &lt; \theta &lt; 160^\circ$</td>
<td></td>
</tr>
<tr>
<td>Time-of-flight measurements</td>
<td>$\sigma_{TOF} \sim 60 , \text{ps}; \sigma_{BCAL} \sim 200 , \text{ps}$</td>
<td></td>
</tr>
<tr>
<td>BCAL time resolution</td>
<td>$\sigma_t^\gamma &lt; (74/\sqrt{E} \oplus 33) , \text{ps}$</td>
<td></td>
</tr>
<tr>
<td><strong>Photon detection</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy measurements</td>
<td>$2^\circ &lt; \theta &lt; 120^\circ$</td>
<td></td>
</tr>
<tr>
<td>FCAL energy resolution ($E &gt; 60 , \text{MeV}$)</td>
<td>$\sigma_E/E = (5.7/\sqrt{E} \oplus 2.0)%$</td>
<td></td>
</tr>
<tr>
<td>BCAL energy resolution ($E &gt; 60 , \text{MeV}$)</td>
<td>$\sigma_E/E = (5.54/\sqrt{E} \oplus 1.6)%$</td>
<td></td>
</tr>
<tr>
<td>FCAL position resolution</td>
<td>$\sigma_{x,y} = (0.64/\sqrt{E}) , \text{cm}$</td>
<td></td>
</tr>
<tr>
<td>BCAL position resolution</td>
<td>$\sigma_z = (0.5/\sqrt{E}) , \text{cm}$</td>
<td></td>
</tr>
<tr>
<td><strong>DAQ/trigger</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 1</td>
<td>$&lt; 200 , \text{kHz}$</td>
<td></td>
</tr>
<tr>
<td>Level 3 event rate to tape</td>
<td>$\sim 15 , \text{kHz}$</td>
<td></td>
</tr>
<tr>
<td>Data rate</td>
<td>$300 , \text{MB/s}$</td>
<td></td>
</tr>
<tr>
<td><strong>Electronics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fully pipelined</td>
<td>$250/125 , \text{MHz fADCs, TDCs}$</td>
<td></td>
</tr>
<tr>
<td><strong>Photon flux</strong></td>
<td></td>
<td>$10^7/10^8 , \gamma/\text{s}$</td>
</tr>
</tbody>
</table>

7/3/2013

Yi Qiang - Physics Program at JLab Hall-D - 5th Hadron Workshop, China
**L1 Trigger System**

**Subsystem Processor: L1**

- **Global Trigger Crate:**
  - Subsystem Energy Sum & Hit Pattern (10Gbps to GTP)

- Sub-System-Processor (SSP) consolidates multiple crate subsystems & report final subsystem quantity to Global-Trigger-Processor (GTP)

- 32bit quantity every 4ns

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**L1 Subsystems (# Crates):**

- FCAL (11)
- BCAL (16)
- Tagger (2)
- ST (1)
- TOF (2)
Experimental Evidence for $1^{-+}$ Exotic Hybrids

- Several candidates for the $\pi_1(1^{-+})$ in the literature at 1400, 1600 and 2000 MeV: some reported by multiple experiments
  - Interpretation of data has received much discussion in community
  - Recent review: Meyer and Van Haarlem, arXiv:1004.5516 (PRC 82, 025208)
- $\pi_1(1600)$ appears to be most robust: multiple decay modes and experiments
  - Reported by COMPASS in $\rho\pi$
  - Handling $\pi_2$ background in $\rho\pi$ was a contentious issue in E852
  - Dominant signal in $\pi p \rightarrow \eta'\pi n$ (E852); needed to fit $\chi_c \rightarrow \eta'\pi\pi$ (CLEO-c)
- Understanding is not likely to come from studying this state alone: find neighboring exotics and non-exotic hybrids
### Decomposition of Total Cross Section

- $E_\gamma = 9.3$ GeV

<table>
<thead>
<tr>
<th>Topology</th>
<th>$\sigma$ ((\mu b))</th>
<th>% of $\sigma$ with neutrals</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-prong</td>
<td>8.5 ± 1.1</td>
<td>100</td>
</tr>
<tr>
<td>3-prong</td>
<td>64.1 ± 1.5</td>
<td>76 ± 3</td>
</tr>
<tr>
<td>5-prong</td>
<td>34.2 ± 0.9</td>
<td>86 ± 4</td>
</tr>
<tr>
<td>7-prong</td>
<td>6.8 ± 0.3</td>
<td>86 ± 6</td>
</tr>
<tr>
<td>9-prong</td>
<td>0.61 ± 0.08</td>
<td>87 ± 21</td>
</tr>
<tr>
<td>With visible strange decay</td>
<td>9.8 ± 0.4</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>124.0 ± 2.5</td>
<td>82 ± 4</td>
</tr>
</tbody>
</table>

Approximately the 70% of total cross section in the energy region $E_\gamma = 7 – 12$ GeV has multiple neutrals and is completely unexplored.
Sensitivity Test using PWA Tools

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

generated waves

\[ a_1(1260) \rightarrow \rho \pi \quad (S - \text{wave}) \]
\[ a_2(1320) \rightarrow \rho \pi \quad (D - \text{wave}) \]
\[ \pi_1(1600) \rightarrow \rho \pi \quad (P - \text{wave}) \]
\[ \pi_2(1670) \rightarrow f_2 \pi \quad (S - \text{wave}) \]
\[ \pi_2(1670) \rightarrow \rho \pi \quad (P - \text{wave}) \]

1+ exotic wave
generated with 1.6% relative strength

Corresponds to 3.5 hours GlueX data, full detector simulation and reconstruction
Event Rates

Use track reconstruction efficiency based on software performance and final states coupled with estimated cross sections.

<table>
<thead>
<tr>
<th>Final State</th>
<th>Cross Section $(\mu b)$</th>
<th>Phase I-III $(x 10^6)$</th>
<th>Phase IV $(x 10^6)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^+\pi^-\pi^0$</td>
<td>10</td>
<td>300</td>
<td>3000</td>
</tr>
<tr>
<td>$\pi^+\pi^-\pi^+$</td>
<td>4</td>
<td>120</td>
<td>1200</td>
</tr>
<tr>
<td>$\omega_3\pi\pi\pi$</td>
<td>0.2</td>
<td>4</td>
<td>40</td>
</tr>
<tr>
<td>$\omega_\gamma\pi\pi\pi$</td>
<td>0.2</td>
<td>0.6</td>
<td>6</td>
</tr>
<tr>
<td>$\eta_{\gamma\gamma}\pi\pi\pi$</td>
<td>0.2</td>
<td>3</td>
<td>30</td>
</tr>
<tr>
<td>$\eta_{\gamma\gamma}\pi\pi\pi\pi$</td>
<td>0.2</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>$\eta_{\pi\pi\pi\pi}$</td>
<td>0.1</td>
<td>0.3</td>
<td>3</td>
</tr>
<tr>
<td>$KK\pi\pi$</td>
<td>0.5</td>
<td>4</td>
<td>40</td>
</tr>
<tr>
<td>$KK\pi$</td>
<td>0.1</td>
<td>1</td>
<td>10</td>
</tr>
</tbody>
</table>

A factor 10 increase in statistics allows access to small signals from initial running.
# GlueX Data Rates

<table>
<thead>
<tr>
<th></th>
<th>Front End DAQ Rate</th>
<th>Event Size</th>
<th>L1 Trigger Rate</th>
<th>Bandwidth to mass Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GlueX</strong></td>
<td>3 GB/s</td>
<td>15 kB</td>
<td>200 kHz</td>
<td>300 MB/s</td>
</tr>
<tr>
<td><strong>CLAS12</strong></td>
<td>0.1 GB/s</td>
<td>20 kB</td>
<td>10 kHz</td>
<td>100 MB/s</td>
</tr>
<tr>
<td><strong>ALICE</strong></td>
<td>500 GB/s</td>
<td>2,500 kB</td>
<td>200 kHz</td>
<td>200 MB/s</td>
</tr>
<tr>
<td><strong>ATLAS</strong></td>
<td>113 GB/s</td>
<td>1,500 kB</td>
<td>75 kHz</td>
<td>300 MB/s</td>
</tr>
<tr>
<td><strong>CMS</strong></td>
<td>200 GB/s</td>
<td>1,000 kB</td>
<td>100 kHz</td>
<td>100 MB/s</td>
</tr>
<tr>
<td><strong>LHCb</strong></td>
<td>40 GB/s</td>
<td>40 kB</td>
<td>1000 kHz</td>
<td>100 MB/s</td>
</tr>
<tr>
<td><strong>STAR</strong></td>
<td>50 GB/s</td>
<td>1,000 kB</td>
<td>0.6 kHz</td>
<td>450 MB/s</td>
</tr>
<tr>
<td><strong>PHENIX</strong></td>
<td>0.9 GB/s</td>
<td>~60 kB</td>
<td>~ 15 kHz</td>
<td>450 MB/s</td>
</tr>
</tbody>
</table>

* Jeff Landgraf Private Comm. 2/11/2010
** CHEP2006 talk Martin L. Purschke. current capability is 800MB/s peak, 500MB/s sustained (priv. comm. 2/14/2010)
Experimental status of exotic $1^{-+} \pi(1600)$

**VES**
$$ \pi^- A \rightarrow \pi^- b_1 A $$
$$ \pi^- f_1 A $$
$$ \pi^- \eta' A $$

**E852**
$$ \pi^- p \rightarrow \rho \pi^- p $$
$$ b_1 \pi^- p $$
$$ f_1 \pi^- p $$
$$ \eta' \pi^- p $$

**Crystal Barrel**
$$ \bar{p}n \rightarrow b_1 \pi^- $$

**E852-IU**
$$ \pi^- p \nrightarrow (\rho \pi^-)_{\pi_1 p} $$
$$ (\rho^- \pi^0)_{\pi_1 p} $$

**CLAS**
$$ \gamma p \nrightarrow (\rho \pi^0)_{\pi_1 n} $$

**COMPASS**
$$ \pi^- A \rightarrow \rho \pi^- A $$

**CLEO-c**
$$ \psi(2S) \rightarrow \gamma \chi_{c1}, \quad \chi_{c1} \rightarrow \eta' \pi^+ \pi^- $$

*For review see Meyer PRC 82 (2010) 025208*
Cascade Spectroscopy

- Information is limited
  - $J^p$ is only known for 3 states
  - PDG: Nothing of significance has been added since 1988
  - Expectations that many are narrow

- Experimentally challenging
  - Produced through hyperon decay
  - Many-particle final states including kaons
  - Small cross sections

- GlueX acceptance and rates are ideal
  - Parasitic to the main GlueX project
  - The baseline GlueX detector can provide pure kaonic event samples with good efficiency for some channels

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**PDG 2012**

\[ \Xi(1320) \quad J^p = (1/2)^+ \quad **** \]

\[ \Xi^*(1530) \quad J^p = (3/2)^+ \quad **** \]

\[ \Xi^*(1620) \quad J^p = (?/2)^? \quad * \]

\[ \Xi^*(1690) \quad J^p = (?/2)^? \quad *** \]

\[ \Xi^*(1820) \quad J^p = (3/2)^- \quad *** \]

\[ \Xi^*(1950) \quad J^p = (?/2)^? \quad *** \]

\[ \Xi^*(2030) \quad J^p = (?/2)^? \quad *** \]

\[ \Xi^*(2120) \quad J^p = (?/2)^? \quad * \]

\[ \Xi^*(2250) \quad J^p = (?/2)^? \quad ** \]

\[ \Xi^*(2370) \quad J^p = (?/2)^? \quad ** \]

\[ \Xi^*(2500) \quad J^p = (?/2)^? \quad * \]