The First Two Years of GlueX Physics

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THE HYBRID MESONS

J^{PC}	$S_{q\bar{q}}$	Particle Name			
		$u\bar{d}$,$d\bar{u}$	$u\bar{u}+d\bar{d}$	$s\bar{s}$	
1^{++}	$S=0$	a_1	f_1	f_1'	non-exotic
1^{--}	$S=0$	ρ_1	ω_1	ϕ_1	non-exotic
0^{-+}	$S=1$	π_0	η_0	η_0'	non-exotic
0^{+-}	$S=1$	b_0	h_1	h_1'	*exotic*
1^{-+}	$S=1$	π_1	η_1	η_1'	*exotic*
1^{+-}	$S=1$	b_1	h_1	h_1'	non-exotic
2^{-+}	$S=1$	π_2	η_2	η_2'	non-exotic
2^{+-}	$S=1$	b_2	h_2	h_2'	*exotic*

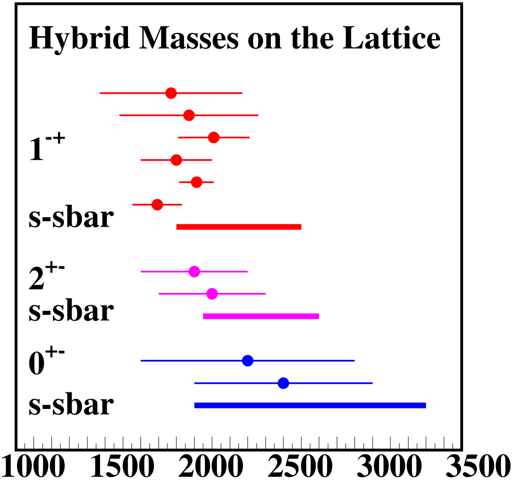
TABLE: A list of the particles in the eight nonets of predicted hybrid mesons. The six nonets with quark and antiquark in an $S=1$ state are the most likely to be produced in photo production. Of these $S=1$ states, half have exotic quantum numbers. Not shown in this table are the strangeness 1 kaonic states.

HYBRID MESON MASSES

Author		1^{-+} Mass (GeV/c^2)	
Collab.	Year	$u\bar{u}/d\bar{d}$	$s\bar{s}$
UKQCD	(1997)	1.87 ± 0.20	2.0 ± 0.2
MILC	(1997)	$1.97 \pm 0.09 \pm 0.30$	$2.170 \pm 0.080 \pm 0.30$
MILC	(1999)	$2.11 \pm 0.10 \pm (sys)$	
SESAM	(1998)	1.9 ± 0.20	
Mei& Luo	(2003)	$2.013 \pm 0.026 \pm 0.071$	
Bernard *et al.*	(2004)	1.792 ± 0.139	2.100 ± 0.120

Multiplet	J^{PC}	Mass
π_1	1^{-+}	$1.9 \pm 0.2\ GeV/c^2$
b_2	2^{+-}	$2.0 \pm 0.11\ GeV/c^2$
b_0	0^{+-}	$2.3 \pm 0.6\ GeV/c^2$

HYBRID MESON MASSES



HYBRID MESON DECAYS

- A non-exhaustive list of hybrid decays. Many of these will probably be accessible in the first GlueX data.
- *Favored* decay in the flux-tube model.

Hybrid	Allowed Decays	Favored Decays
π_1	$\rho\pi$, πb_1, πf_2, ηa_2	$\rho\pi$, πb_1
η_1, η_1'	πa_2, ηf_2	
b_2	$\pi\omega$, $\pi\phi$, $\eta\rho$, πa_2	πa_2
h_2, h_2'	$\rho\pi$, $\eta\omega$, $\eta\phi$, ωf_2, πb_1	$\rho\pi$, πb_1
b_0		
h_0, h_0'	πb_1	πb_1

MEASURED PHOTO PRODUCTION CROSS SECTIONS

Measured photo production cross sections for $E_\gamma \sim 9\,GeV$. Most of these measurements are based on at most a few thousand events, so errors can be large.

Reaction	σ
$\gamma p \longrightarrow p\pi^+\pi^- X^{neut}$	$20\mu b$
$\gamma p \longrightarrow p\pi^+\pi^-\pi^\circ$	$10\mu b$
$\gamma p \longrightarrow n\pi^+\pi^+\pi^- X^{neut}$	$20\mu b$
$\gamma p \longrightarrow pK^+K^- X^{neut}$	$1\mu b$
$\gamma p \longrightarrow f_2(1270)p$	$1\mu b$
$\gamma p \longrightarrow a_2^+(1320)n$	$1\mu b$
$\gamma p \longrightarrow b_1^\circ(1235)p$	$1\mu b$
$\gamma p \longrightarrow \rho'(1465)p$	$1\mu b$
$\gamma p \longrightarrow \rho(770)p$	$20\mu b$
$\gamma p \longrightarrow \omega p$	$2\mu b$
$\gamma p \longrightarrow \phi p$	$0.4\mu b$

MEASURED PHOTO PRODUCTION CROSS SECTIONS

The a_2 cross section is large, and will turn out to be a very good reaction with which to understand systematics.

Reaction	σ
$\gamma p \rightarrow p\pi^+\pi^- X^{neut}$	$20\mu b$
$\gamma p \rightarrow p\pi^+\pi^-\pi^\circ$	$10\mu b$
$\gamma p \rightarrow n\pi^+\pi^+\pi^- X^{neut}$	$20\mu b$
$\gamma p \rightarrow pK^+K^- X^{neut}$	$1\mu b$
$\gamma p \rightarrow f_2(1270)p$	$1\mu b$
$\gamma p \rightarrow a_2^+(1320)n$	$1\mu b$
$\gamma p \rightarrow b_1^\circ(1235)p$	$1\mu b$
$\gamma p \rightarrow \rho'(1465)p$	$1\mu b$
$\gamma p \rightarrow \rho(770)p$	$20\mu b$
$\gamma p \rightarrow \omega p$	$2\mu b$
$\gamma p \rightarrow \phi p$	$0.4\mu b$

MEASURED PHOTO PRODUCTION CROSS SECTIONS

Vector meson production and polarization transfer are likely to be good reactions with which to understand polarization.

Reaction	σ
$\gamma p \longrightarrow p\pi^+\pi^- X^{neut}$	$20\mu b$
$\gamma p \longrightarrow p\pi^+\pi^-\pi^\circ$	$10\mu b$
$\gamma p \longrightarrow n\pi^+\pi^+\pi^- X^{neut}$	$20\mu b$
$\gamma p \longrightarrow pK^+K^- X^{neut}$	$1\mu b$
$\gamma p \longrightarrow f_2(1270)p$	$1\mu b$
$\gamma p \longrightarrow a_2^+(1320)n$	$1\mu b$
$\gamma p \longrightarrow b_1^\circ(1235)p$	$1\mu b$
$\gamma p \longrightarrow \rho'(1465)p$	$1\mu b$
$\gamma p \longrightarrow \rho(770)p$	$20\mu b$
$\gamma p \longrightarrow \omega p$	$2\mu b$
$\gamma p \longrightarrow \phi p$	$0.4\mu b$

ESTIMATED PHOTO PRODUCTION CROSS SECTIONS

$\gamma p \longrightarrow p\pi^+\pi^-\pi^\circ$	5–10μb
$\gamma p \longrightarrow n\pi^+\pi^+\pi^-$	5–10μb
$\gamma p \longrightarrow p\pi^+\pi^\circ\pi^\circ$	5–10μb
$\gamma p \longrightarrow p\pi^+\pi^-\pi^+\pi^-$	$1-3\mu b$
$\gamma p \longrightarrow p\pi^+\pi^-\pi^\circ\pi^\circ$	$1-3\mu b$
$\gamma p \longrightarrow p\pi^\circ\pi^\circ\pi^\circ\pi^\circ$	$1-3\mu b$
$\gamma p \longrightarrow n\pi^+\pi^-\pi^+\pi^\circ$	$1-3\mu b$
$\gamma p \longrightarrow n\pi^+\pi^\circ\pi^\circ\pi^\circ$	$1-3\mu b$
$\gamma p \longrightarrow p\pi^+\pi^-\pi^+\pi^-\pi^\circ$	$1-3\mu b$
$\gamma p \longrightarrow p\pi^+\pi^-\pi^\circ\pi^\circ\pi^\circ$	$1-3\mu b$
$\gamma p \longrightarrow p\pi^\circ\pi^\circ\pi^\circ\pi^\circ\pi^\circ$	$1-3\mu b$
$\gamma p \longrightarrow n\pi^+\pi^-\pi^+\pi^-\pi^+$	$1-3\mu b$
$\gamma p \longrightarrow n\pi^+\pi^-\pi^+\pi^\circ\pi^\circ$	$1-3\mu b$
$\gamma p \longrightarrow n\pi^+\pi^\circ\pi^\circ\pi^\circ\pi^\circ$	$1-3\mu b$

$\gamma p \longrightarrow p\pi^\circ\omega$	1 μb
$\gamma p \longrightarrow n\pi^+\omega$	1 μb
$\gamma p \longrightarrow p\pi^+\pi^-\omega$	0.1–0.5 μb
$\gamma p \longrightarrow p\pi^\circ\pi^\circ\omega$	0.1–0.5 μb
$\gamma p \longrightarrow n\pi^+\pi^\circ\omega$	0.1–0.5 μb
$\gamma p \longrightarrow p\pi^+\pi^-\eta$	0.2–1.0 μb
$\gamma p \longrightarrow p\pi^\circ\pi^\circ\eta$	0.2–1.0 μb
$\gamma p \longrightarrow p\eta\eta$	0.05–0.2 μb
$\gamma p \longrightarrow p\omega\eta$	0.05–0.2 μb
$\gamma p \longrightarrow p\omega\omega$	0.05–0.2 μb
$\gamma p \longrightarrow p\eta\eta\prime$	0.05–0.2 μb

ESTIMATED PHOTO PRODUCTION CROSS SECTIONS

$\gamma p \longrightarrow p\pi^+\pi^-\pi^\circ$	$5–10\mu b$
$\gamma p \longrightarrow n\pi^+\pi^+\pi^-$	$5–10\mu b$
$\gamma p \longrightarrow p\pi^+\pi^\circ\pi^\circ$	$5–10\mu b$
$\gamma p \longrightarrow p\pi^+\pi^-\pi^+\pi^-$	$1-3\mu b$
$\gamma p \longrightarrow p\pi^+\pi^-\pi^\circ\pi^\circ$	$1-3\mu b$
$\gamma p \longrightarrow p\pi^\circ\pi^\circ\pi^\circ\pi^\circ$	$1-3\mu b$
$\gamma p \longrightarrow n\pi^+\pi^-\pi^+\pi^\circ$	$1-3\mu b$
$\gamma p \longrightarrow n\pi^+\pi^\circ\pi^\circ\pi^\circ$	$1-3\mu b$
$\gamma p \longrightarrow p\pi^+\pi^-\pi^+\pi^-\pi^\circ$	$1-3\mu b$
$\gamma p \longrightarrow p\pi^+\pi^-\pi^\circ\pi^\circ\pi^\circ$	$1-3\mu b$
$\gamma p \longrightarrow p\pi^\circ\pi^\circ\pi^\circ\pi^\circ\pi^\circ$	$1-3\mu b$
$\gamma p \longrightarrow n\pi^+\pi^-\pi^+\pi^-\pi^+$	$1-3\mu b$
$\gamma p \longrightarrow n\pi^+\pi^-\pi^+\pi^\circ\pi^\circ$	$1-3\mu b$
$\gamma p \longrightarrow n\pi^+\pi^\circ\pi^\circ\pi^\circ\pi^\circ$	$1-3\mu b$

$\gamma p \longrightarrow p\pi^\circ\omega$	$1\,\mu b$
$\gamma p \longrightarrow n\pi^+\omega$	$1\,\mu b$
$\gamma p \longrightarrow p\pi^+\pi^-\omega$	$0.1–0.5\,\mu b$
$\gamma p \longrightarrow p\pi^\circ\pi^\circ\omega$	$0.1–0.5\,\mu b$
$\gamma p \longrightarrow n\pi^+\pi^\circ\omega$	$0.1–0.5\,\mu b$
$\gamma p \longrightarrow p\pi^+\pi^-\eta$	$0.2–1.0\,\mu b$
$\gamma p \longrightarrow p\pi^\circ\pi^\circ\eta$	$0.2–1.0\,\mu b$
$\gamma p \longrightarrow p\eta\eta$	$0.05–0.2\,\mu b$
$\gamma p \longrightarrow p\omega\eta$	$0.05–0.2\,\mu b$
$\gamma p \longrightarrow p\omega\omega$	$0.05–0.2\,\mu b$
$\gamma p \longrightarrow p\eta\eta\prime$	$0.05–0.2\,\mu b$

EVENT RATE ESTIMATES

The event rate, $\dot{N}_{evt}$ is given as:

$$\begin{aligned}\dot{N}_{evt} &= \sigma \cdot N_{targ} \cdot \dot{N}_{\gamma} \\ N_{evt} &= \dot{N}_{evt} \cdot \mathrm{time}\end{aligned}$$

where σ is the photo production cross section, N_{targ}, $(1.26\, b^{-1})$, is the number of scattering centers per unit area, and $\dot{N}_{\gamma}$ is the tagged photon rate on target, (from $10^7\, s^{-1}$ to $10^8\, s^{-1}$).

- Assume initial photon rates are $10^7\, s^{-1}$.
- Assume "time" is 26 weeks with 30% efficiency, $(5 \times 10^6\, s/yr)$.
- Assume overall event efficiency is 72%.

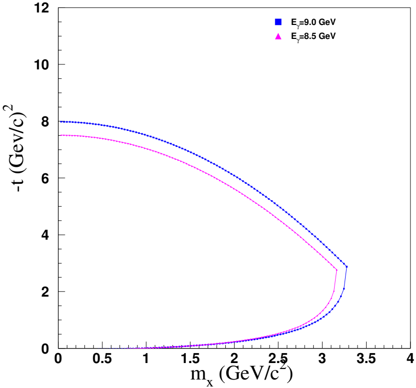
EVENT RATE ESTIMATES

We assume various photo production cross sections and estimate how many events are reconstructed in one year (26 weeks, 30%) under the previous assumptions.

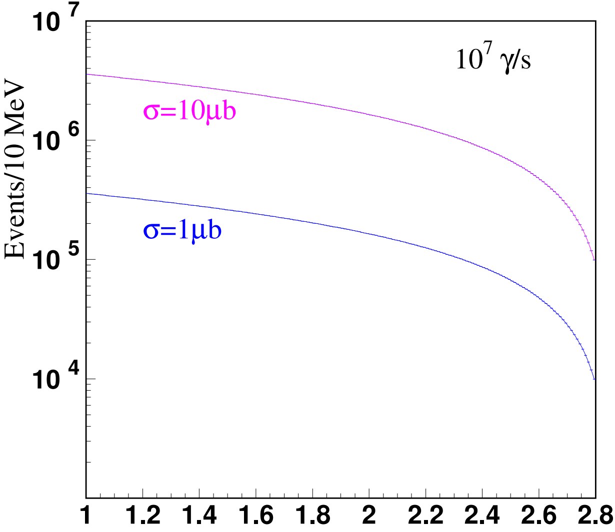
$\sigma\ \mu b$	N_γ	Events		
		Trig. Rate	To Tape	Reconstructed
$1\ \mu b$	$1\times10^7\gamma/s$	$12.6\ Hz$	$6.3\times10^7\,\mathrm{yr}^{-1}$	$4.5\times10^7\,\mathrm{yr}^{-1}$
$1\ \mu b$	$5\times10^7\gamma/s$	$63\ Hz$	$3.2\times10^8\,\mathrm{yr}^{-1}$	$2.3\times10^8\,\mathrm{yr}^{-1}$
$1\ \mu b$	$1\times10^8\gamma/s$	$126\ Hz$	$6.3\times10^8\,\mathrm{yr}^{-1}$	$4.5\times10^8\,\mathrm{yr}^{-1}$
$.1\ \mu b$	$1\times10^7\gamma/s$	$1.26\ Hz$	$6.3\times10^6\,\mathrm{yr}^{-1}$	$4.5\times10^6\,\mathrm{yr}^{-1}$
$.1\ \mu b$	$5\times10^7\gamma/s$	$6.3\ Hz$	$3.2\times10^7\,\mathrm{yr}^{-1}$	$2.3\times10^7\,\mathrm{yr}^{-1}$
$.1\ \mu b$	$1\times10^8\gamma/s$	$12.6\ Hz$	$6.3\times10^7\,\mathrm{yr}^{-1}$	$4.5\times10^7\,\mathrm{yr}^{-1}$
$1\ nb$	$1\times10^7\gamma/s$	$0.0126\ Hz$	$6.3\times10^4\,\mathrm{yr}^{-1}$	$4.5\times10^4\,\mathrm{yr}^{-1}$
$1\ nb$	$5\times10^7\gamma/s$	$0.063\ Hz$	$3.2\times10^5\,\mathrm{yr}^{-1}$	$2.3\times10^5\,\mathrm{yr}^{-1}$
$1\ nb$	$1\times10^8\gamma/s$	$0.126\ Hz$	$6.3\times10^5\,\mathrm{yr}^{-1}$	$4.5\times10^5\,\mathrm{yr}^{-1}$

EVENT DISTRIBUTIONS

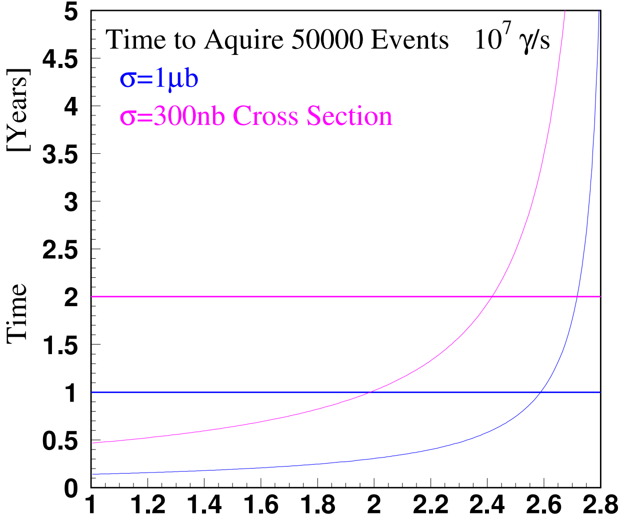
Assume that the events are produced with an $e^{-5|t|}$ weighting from $| t |_{min}$ to $| t |_{max}$. Integrate up the exponential over the valid range and estimate the number of events in bins of a given width. 21% are in the lowest mass bin while 0.3% are in the highest mass bin.



EVENT DISTRIBUTIONS IN 10 *MeV* BINS



EVENT DISTRIBUTIONS IN 10 *MeV* BINS



THE a_2 MESON

The cross sections for a_2 production are on the order of $1\mu b$, and the mass of the a_2 is where we have very large statistics. This makes the production of the a_2 a good detector test bed.

$$\begin{array}{lll}
a_2^+(1320) \rightarrow & \rho\pi \rightarrow & \pi^+\pi^+\pi^- \\
 & & \pi^+\pi^\circ\pi^\circ \\
 & \pi^+\eta \rightarrow & \pi^+\gamma\gamma \\
 & & \pi^+\pi^+\pi^-\pi^\circ \\
 & & \pi^+\pi^\circ\pi^\circ\pi^\circ \\
 & K^+K_S \rightarrow & K^+\pi^+\pi^- \\
 & & K^+\pi^\circ\pi^\circ \\
 & \pi^+\eta\prime \rightarrow & \pi^+\pi^+\pi^-\gamma\gamma
\end{array}$$

These final states fully exercise most of the detector with high statistics in a very short period of time.

VECTOR MESON PRODUCTION

- Relatively large cross sections for vector meson production.
- Angular distribution of the decay measures polarization.
- Should be able to measure the beam polarization.

$\gamma p \rightarrow \rho(770) p$	$20 \mu b$
$\gamma p \rightarrow \omega p$	$2 \mu b$
$\gamma p \rightarrow \phi p$	$0.4 \mu b$

EXCITED VECTOR MESON PRODUCTION

The higher-mass vector mesons should be prolifically produced in photo production. However, the states are not well understood. There is a great deal of ambiguity in masses and decay rates, and a missing ϕ state. Clean measurements of these states would be an important an important result in understanding normal $q\bar{q}$ states, as well as possible hybrid mixtures.

$$\sigma\left[\gamma p \rightarrow \rho(1465) p\right] \quad \approx \quad 1\,\mu b$$

Particle Name	Mass GeV/c^2	Width GeV/c^2	Decays
$\rho(1450)$	1.465	0.400	$\pi\pi$, 4π, $\omega\pi$
$\rho(1700)$	1.720	0.250	$\pi\pi$, 4π
$\omega(1420)$	1.400	0.250	$\rho\pi$, $\omega\pi\pi$
$\omega(1650)$	1.670	0.315	$\rho\pi$, $\omega\pi\pi$
$\phi(1680)$	1.680	0.150	$K\overline{K}^{*} + cc$, $K\overline{K}$

EXOTIC HYBRID MESON SEARCHES

The three channels, $\pi\pi\pi$, $\omega\pi\pi$ and $\eta\pi\pi$ are a good staring point for searches for exotic hybrids.

- The cross sections times branching fraction are reasonable.
- Multiple isospin states are available.
- Three particle final states allow *simplified* analysis.

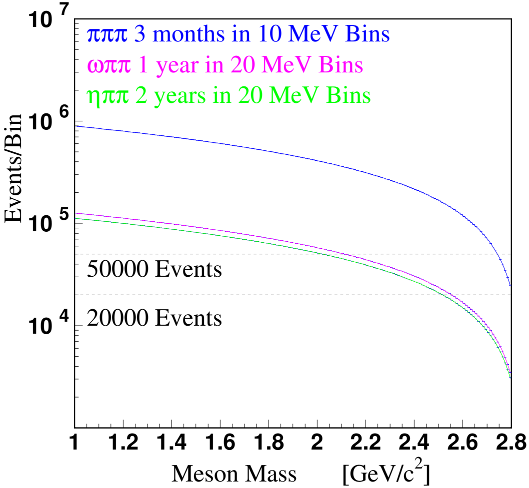
Reaction	σ	Fin St.	BR
$\gamma p \rightarrow p\pi\pi\pi$	$10\mu b$	3π	1.0
$\gamma p \rightarrow n\pi^+\pi\pi$	$10\mu b$	3π	1.0
$\gamma p \rightarrow p\pi\pi\omega$	$0.2\mu b$	3π	0.88
$\gamma p \rightarrow n\pi^+\pi\omega$	$0.2\mu b$	3π	0.88
$\gamma p \rightarrow p\pi\pi\eta$	$0.2\mu b$	$\gamma\gamma$	0.37
$\gamma p \rightarrow n\pi^+\pi\eta$	$0.2\mu b$	$\gamma\gamma$	0.37

The *simpler* decays of exotic hybrids. Color codes show those that couple to $\pi\pi\pi$, $\pi\pi\omega$ and $\pi\pi\eta$ final states. In many cases these are also favored decay modes.

Hybrid	Allowed Decays	Favored Decays
π_1	$\rho\pi$, πb_1, πf_2, ηa_2	$\rho\pi$, πb_1
η_1, η_1'	πa_2, ηf_2	
b_2	$\pi\omega$, $\pi\phi$, $\eta\rho$, πa_2	πa_2
h_2, h_2'	$\rho\pi$, $\eta\omega$, $\eta\phi$, ωf_2, πb_1	$\rho\pi$, πb_1
b_0		
h_0, h_0'	πb_1	πb_1

EXOTIC HYBRID MESON SEARCHES

Hybrid	$\pi\pi\pi$	$\omega\pi\pi$	$\eta\pi\pi$
h_0	yes	yes	
η_1			yes
π_1	yes	yes	
h_2		yes	
b_2	yes		yes



SUMMARY AND CONCLUSIONS

I propose the following pieces in our initial physics program.

- a_2 production and decay.
- Light vector meson photo production.
- Heavy vector meson photo production.
- A search for several hybrids in simple final states.

This program lets us shake down the detector and understand how all the parts works together and calibrate various pieces. We then identify an interesting piece of physics where the data can be collected reasonably quickly. Finally, we have a somewhat longer term piece of physics that carries out a major initial search in our flagship physics program.