

*The First Two Years of GlueX Physics*  
*GlueX Collaboration Meeting, April 2006*

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# OUTLINE

- 1 WHAT NEEDS TO HAPPEN
- 2 HYBRID MESONS
- 3 KNOWN AND ESTIMATED CROSS SECTIONS
- 4 RATE ESTIMATES
- 5 CALIBRATION REACTIONS
- 6 POTENTIAL PHYSICS REACTIONS
- 7 SUMMARY AND CONCLUSIONS

# THE FIRST TWO YEARS

- Engineering Run(s) of the detector
- Data Acquisition and Trigger shake down
- Software shake down
- Calibration of the detector
  - Tagger/ Beam Energy
  - Beam Polarization
  - Drift Chambers
  - Calorimeters
  - Time of Flight
  - PID
- Global event analysis.
- Physics

## 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
$1^{--}$	$S = 0$	$\rho_1$	$\omega_1$	$\phi_1$	non-exotic
$0^{-+}$	$S = 1$	$\pi_0$	$\eta_0$	$\eta_0'$	non-exotic
$0^{+-}$	$S = 1$	$b_0$	$h_1$	$h_1'$	<i>exotic</i>
$1^{-+}$	$S = 1$	$\pi_1$	$\eta_1$	$\eta_1'$	<i>exotic</i>
$1^{+-}$	$S = 1$	$b_1$	$h_1$	$h_1'$	non-exotic
$2^{-+}$	$S = 1$	$\pi_2$	$\eta_2$	$\eta_2'$	non-exotic
$2^{+-}$	$S = 1$	$b_2$	$h_2$	$h_2'$	<i>exotic</i>

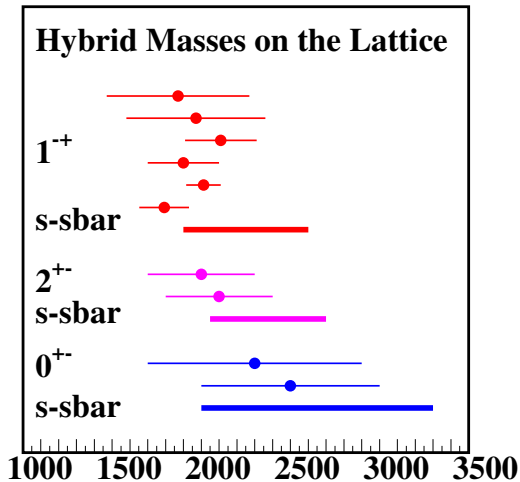
**TABLE:** A list of the particles in the eight nonets of predicted hybrid mesons. The six nonets with quark and antiquark in an  $S = 1$  state are the most likely to be produced in photo production. Of these  $S = 1$  states, half have exotic quantum numbers. Not shown in this table are the strangeness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

## HYBRID MESON MASSES

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

Multiplet	$J^{PC}$	Mass
$\pi_1$	$1^{-+}$	$1.9 \pm 0.2 \text{ GeV}/c^2$
$b_2$	$2^{+-}$	$2.0 \pm 0.11 \text{ GeV}/c^2$
$b_0$	$0^{+-}$	$2.3 \pm 0.6 \text{ GeV}/c^2$

## 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
$\pi_1$	$\rho\pi, \pi b_1, \pi f_2, \eta a_2$	$\rho\pi, \pi b_1$
$\eta_1, \eta'_1$	$\pi a_2, \eta f_2$	
$b_2$	$\pi\omega, \pi\phi, \eta\rho, \pi a_2$	$\pi a_2$
$h_2, h'_2$	$\rho\pi, \eta\omega, \eta\phi, \omega f_2, \pi b_1$	$\rho\pi, \pi b_1$
$b_0$		
$h_0, h'_0$	$\pi b_1$	$\pi b_1$

## MEASURED PHOTO PRODUCTION CROSS SECTIONS

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

Reaction	$\sigma$
$\gamma p \rightarrow p\pi^+\pi^-\chi^{neut}$	$20\mu b$
$\gamma p \rightarrow p\pi^+\pi^-\pi^0$	$10\mu b$
$\gamma p \rightarrow n\pi^+\pi^+\pi^-\chi^{neut}$	$20\mu b$
$\gamma p \rightarrow pK^+K^-\chi^{neut}$	$1\mu b$
$\gamma p \rightarrow f_2(1270)p$	$1\mu b$
$\gamma p \rightarrow a_2^+(1320)n$	$1\mu b$
$\gamma p \rightarrow b_1^0(1235)p$	$1\mu b$
$\gamma p \rightarrow \rho'(1465)p$	$1\mu b$
$\gamma p \rightarrow \rho(770)p$	$20\mu b$
$\gamma p \rightarrow \omega p$	$2\mu b$
$\gamma p \rightarrow \phi p$	$0.4\mu b$



## MEASURED PHOTO PRODUCTION CROSS SECTIONS

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

Reaction	$\sigma$
$\gamma p \rightarrow p\pi^+\pi^-\chi^{neut}$	$20\mu b$
$\gamma p \rightarrow p\pi^+\pi^-\pi^0$	$10\mu b$
$\gamma p \rightarrow n\pi^+\pi^+\pi^-\chi^{neut}$	$20\mu b$
$\gamma p \rightarrow pK^+K^-\chi^{neut}$	$1\mu b$
$\gamma p \rightarrow f_2(1270)p$	$1\mu b$
$\gamma p \rightarrow a_2^+(1320)n$	$1\mu b$
$\gamma p \rightarrow b_1^0(1235)p$	$1\mu b$
$\gamma p \rightarrow \rho'(1465)p$	$1\mu b$
$\gamma p \rightarrow \rho(770)p$	$20\mu b$
$\gamma p \rightarrow \omega p$	$2\mu b$
$\gamma p \rightarrow \phi p$	$0.4\mu b$

## MEASURED PHOTO PRODUCTION CROSS SECTIONS

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

Reaction	$\sigma$
$\gamma p \rightarrow p\pi^+\pi^-\chi^{neut}$	$20\mu b$
$\gamma p \rightarrow p\pi^+\pi^-\pi^0$	$10\mu b$
$\gamma p \rightarrow n\pi^+\pi^+\pi^-\chi^{neut}$	$20\mu b$
$\gamma p \rightarrow pK^+K^-\chi^{neut}$	$1\mu b$
$\gamma p \rightarrow f_2(1270)p$	$1\mu b$
$\gamma p \rightarrow a_2^+(1320)n$	$1\mu b$
$\gamma p \rightarrow b_1^0(1235)p$	$1\mu b$
$\gamma p \rightarrow \rho'(1465)p$	$1\mu b$
$\gamma p \rightarrow \rho(770)p$	$20\mu b$
$\gamma p \rightarrow \omega p$	$2\mu b$
$\gamma p \rightarrow \phi p$	$0.4\mu b$

## ESTIMATED PHOTO PRODUCTION CROSS SECTIONS

$\gamma p \rightarrow p\pi^+\pi^-\pi^0$	5–10 $\mu b$
$\gamma p \rightarrow n\pi^+\pi^+\pi^-$	5–10 $\mu b$
$\gamma p \rightarrow p\pi^+\pi^0\pi^0$	5–10 $\mu b$
$\gamma p \rightarrow p\pi^+\pi^-\pi^+\pi^-$	1 – 3 $\mu b$
$\gamma p \rightarrow p\pi^+\pi^-\pi^0\pi^0$	1 – 3 $\mu b$
$\gamma p \rightarrow p\pi^0\pi^0\pi^0\pi^0$	1 – 3 $\mu b$
$\gamma p \rightarrow n\pi^+\pi^-\pi^+\pi^0$	1 – 3 $\mu b$
$\gamma p \rightarrow n\pi^+\pi^0\pi^0\pi^0$	1 – 3 $\mu b$
$\gamma p \rightarrow p\pi^+\pi^-\pi^+\pi^-\pi^0$	1 – 3 $\mu b$
$\gamma p \rightarrow p\pi^+\pi^-\pi^0\pi^0\pi^0$	1 – 3 $\mu b$
$\gamma p \rightarrow p\pi^0\pi^0\pi^0\pi^0\pi^0$	1 – 3 $\mu b$
$\gamma p \rightarrow n\pi^+\pi^-\pi^+\pi^-\pi^+$	1 – 3 $\mu b$
$\gamma p \rightarrow n\pi^+\pi^-\pi^+\pi^0\pi^0$	1 – 3 $\mu b$
$\gamma p \rightarrow n\pi^+\pi^0\pi^0\pi^0\pi^0$	1 – 3 $\mu b$

$\gamma p \rightarrow p\pi^0\omega$	1 $\mu b$
$\gamma p \rightarrow n\pi^+\omega$	1 $\mu b$
$\gamma p \rightarrow p\pi^+\pi^-\omega$	0.1–0.5 $\mu b$
$\gamma p \rightarrow p\pi^0\pi^0\omega$	0.1–0.5 $\mu b$
$\gamma p \rightarrow n\pi^+\pi^0\omega$	0.1–0.5 $\mu b$
$\gamma p \rightarrow p\pi^+\pi^-\eta$	0.2–1.0 $\mu b$
$\gamma p \rightarrow p\pi^0\pi^0\eta$	0.2–1.0 $\mu b$
$\gamma p \rightarrow p\eta\eta$	0.05–0.2 $\mu b$
$\gamma p \rightarrow p\omega\eta$	0.05–0.2 $\mu b$
$\gamma p \rightarrow p\omega\omega$	0.05–0.2 $\mu b$
$\gamma p \rightarrow p\eta\eta'$	0.05–0.2 $\mu b$

## ESTIMATED PHOTO PRODUCTION CROSS SECTIONS

$\gamma p \rightarrow p\pi^+\pi^-\pi^0$	5–10 $\mu b$
$\gamma p \rightarrow n\pi^+\pi^+\pi^-$	5–10 $\mu b$
$\gamma p \rightarrow p\pi^+\pi^0\pi^0$	5–10 $\mu b$
$\gamma p \rightarrow p\pi^+\pi^-\pi^+\pi^-$	1 – 3 $\mu b$
$\gamma p \rightarrow p\pi^+\pi^-\pi^0\pi^0$	1 – 3 $\mu b$
$\gamma p \rightarrow p\pi^0\pi^0\pi^0\pi^0$	1 – 3 $\mu b$
$\gamma p \rightarrow n\pi^+\pi^-\pi^+\pi^0$	1 – 3 $\mu b$
$\gamma p \rightarrow n\pi^+\pi^0\pi^0\pi^0$	1 – 3 $\mu b$
$\gamma p \rightarrow p\pi^+\pi^-\pi^+\pi^-\pi^0$	1 – 3 $\mu b$
$\gamma p \rightarrow p\pi^+\pi^-\pi^0\pi^0\pi^0$	1 – 3 $\mu b$
$\gamma p \rightarrow p\pi^0\pi^0\pi^0\pi^0\pi^0$	1 – 3 $\mu b$
$\gamma p \rightarrow n\pi^+\pi^-\pi^+\pi^-\pi^+$	1 – 3 $\mu b$
$\gamma p \rightarrow n\pi^+\pi^-\pi^+\pi^0\pi^0$	1 – 3 $\mu b$
$\gamma p \rightarrow n\pi^+\pi^0\pi^0\pi^0\pi^0$	1 – 3 $\mu b$

$\gamma p \rightarrow p\pi^0\omega$	1 $\mu b$
$\gamma p \rightarrow n\pi^+\omega$	1 $\mu b$
$\gamma p \rightarrow p\pi^+\pi^-\omega$	0.1–0.5 $\mu b$
$\gamma p \rightarrow p\pi^0\pi^0\omega$	0.1–0.5 $\mu b$
$\gamma p \rightarrow n\pi^+\pi^0\omega$	0.1–0.5 $\mu b$
$\gamma p \rightarrow p\pi^+\pi^-\eta$	0.2–1.0 $\mu b$
$\gamma p \rightarrow p\pi^0\pi^0\eta$	0.2–1.0 $\mu b$
$\gamma p \rightarrow p\eta\eta$	0.05–0.2 $\mu b$
$\gamma p \rightarrow p\omega\eta$	0.05–0.2 $\mu b$
$\gamma p \rightarrow p\omega\omega$	0.05–0.2 $\mu b$
$\gamma p \rightarrow p\eta\eta'$	0.05–0.2 $\mu b$

# EVENT RATE ESTIMATES

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

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

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

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

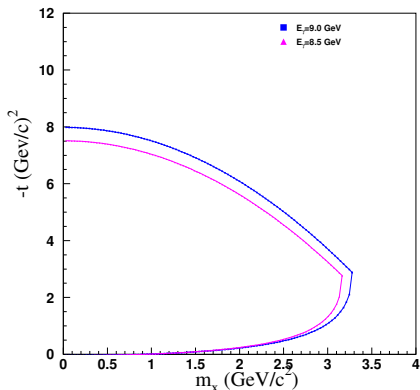
## EVENT RATE ESTIMATES

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

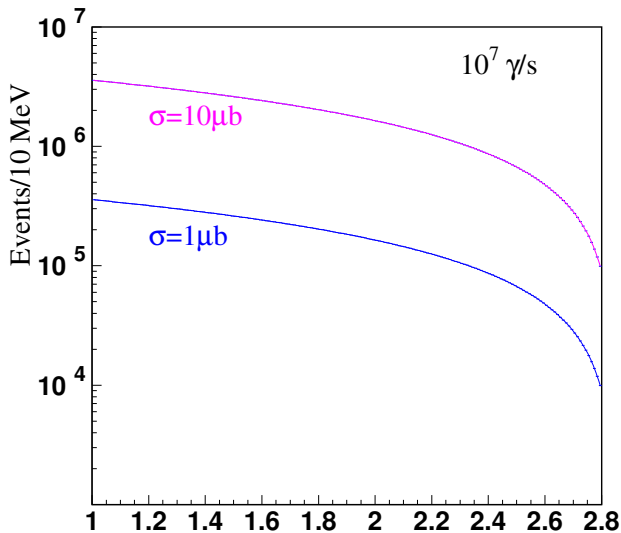
$\sigma \mu b$	$N_\gamma$	Events		
		Trig. Rate	To Tape	Reconstructed
$1 \mu b$	$1 \times 10^7 \gamma/s$	12.6 Hz	$6.3 \times 10^7 \text{ yr}^{-1}$	$4.5 \times 10^7 \text{ yr}^{-1}$
$1 \mu b$	$5 \times 10^7 \gamma/s$	63 Hz	$3.2 \times 10^8 \text{ yr}^{-1}$	$2.3 \times 10^8 \text{ yr}^{-1}$
$1 \mu b$	$1 \times 10^8 \gamma/s$	126 Hz	$6.3 \times 10^8 \text{ yr}^{-1}$	$4.5 \times 10^8 \text{ yr}^{-1}$
$.1 \mu b$	$1 \times 10^7 \gamma/s$	1.26 Hz	$6.3 \times 10^6 \text{ yr}^{-1}$	$4.5 \times 10^6 \text{ yr}^{-1}$
$.1 \mu b$	$5 \times 10^7 \gamma/s$	6.3 Hz	$3.2 \times 10^7 \text{ yr}^{-1}$	$2.3 \times 10^7 \text{ yr}^{-1}$
$.1 \mu b$	$1 \times 10^8 \gamma/s$	12.6 Hz	$6.3 \times 10^7 \text{ yr}^{-1}$	$4.5 \times 10^7 \text{ yr}^{-1}$
$1 nb$	$1 \times 10^7 \gamma/s$	0.0126 Hz	$6.3 \times 10^4 \text{ yr}^{-1}$	$4.5 \times 10^4 \text{ yr}^{-1}$
$1 nb$	$5 \times 10^7 \gamma/s$	0.063 Hz	$3.2 \times 10^5 \text{ yr}^{-1}$	$2.3 \times 10^5 \text{ yr}^{-1}$
$1 nb$	$1 \times 10^8 \gamma/s$	0.126 Hz	$6.3 \times 10^5 \text{ yr}^{-1}$	$4.5 \times 10^5 \text{ yr}^{-1}$

# 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.

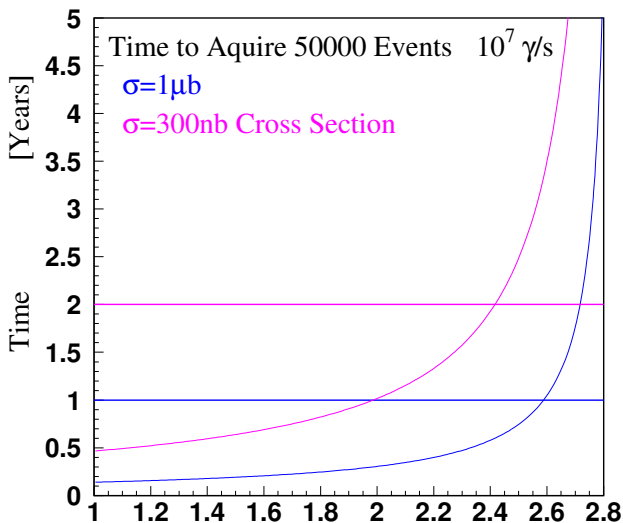


## EVENT DISTRIBUTIONS IN 10 MeV BINS



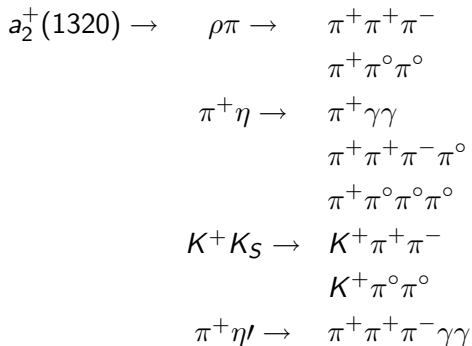


## EVENT DISTRIBUTIONS IN 10 MeV BINS



# 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.



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  $\phi$  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.

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

Particle Name	Mass $GeV/c^2$	Width $GeV/c^2$	Decays
$\rho(1450)$	1.465	0.400	$\pi\pi, 4\pi, \omega\pi$
$\rho(1700)$	1.720	0.250	$\pi\pi, 4\pi$
$\omega(1420)$	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	$K\bar{K}^* + cc, K\bar{K}$

# EXOTIC HYBRID MESON SEARCHES

The three channels,  $\pi\pi\pi$ ,  $\omega\pi\pi$  and  $\eta\pi\pi$  are a good starting 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.

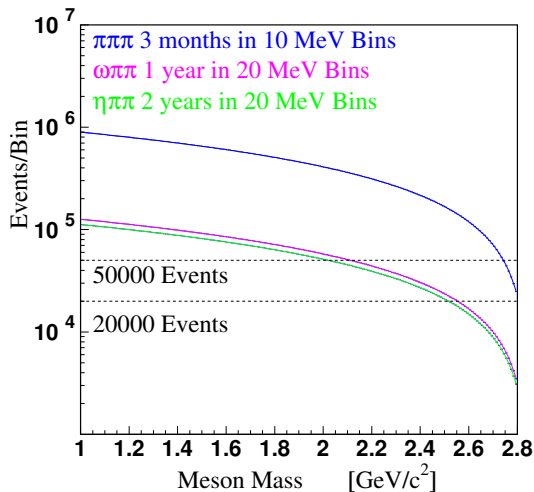
Reaction	$\sigma$	Fin St.	BR
$\gamma p \rightarrow p\pi\pi\pi$	$10\mu b$	$3\pi$	1.0
$\gamma p \rightarrow n\pi^+\pi\pi$	$10\mu b$	$3\pi$	1.0
$\gamma p \rightarrow p\pi\pi\omega$	$0.2\mu b$	$3\pi$	0.88
$\gamma p \rightarrow n\pi^+\pi\omega$	$0.2\mu b$	$3\pi$	0.88
$\gamma p \rightarrow p\pi\pi\eta$	$0.2\mu b$	$\gamma\gamma$	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
$\pi_1$	$\rho\pi$ , $\pi b_1$ , $\pi f_2$ , $\eta a_2$	$\rho\pi$ , $\pi b_1$
$\eta_1, \eta'_1$	$\pi a_2$ , $\eta f_2$	
$b_2$	$\pi\omega$ , $\pi\phi$ , $\eta\rho$ , $\pi a_2$	$\pi a_2$
$h_2, h'_2$	$\rho\pi$ , $\eta\omega$ , $\eta\phi$ , $\omega f_2$ , $\pi b_1$	$\rho\pi$ , $\pi b_1$
$b_0$		
$h_0, h'_0$	$\pi b_1$	$\pi b_1$

## EXOTIC HYBRID MESON SEARCHES

Hybrid	$\pi\pi\pi$	$\omega\pi\pi$	$\eta\pi\pi$
$h_0$		yes	
$\eta_1$			yes
$\pi_1$	yes	yes	
$h_2$	yes	yes	
$b_2$			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.