Production and Decay of Exotic Hybrids in GlueX

GlueX-Doc 4788

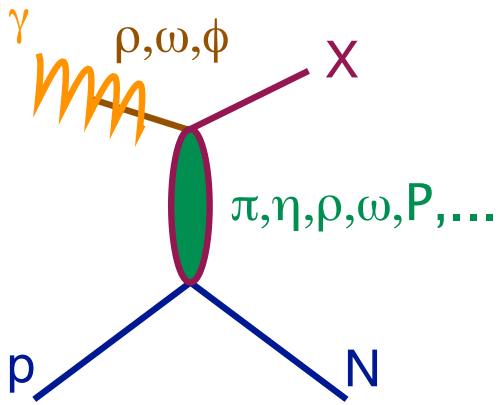
Curtis A. Meyer

December 8, 2020

Purpose of the Document

- Revisit the arguments that we make on production of exotic hybrids with an eye to being more quantitative.

Photoproduction Mechanisms



Simple quantum number counting for production:
$(I^G)J^{PC}$ up to L=2

P = Pomeron exchange

$\rho\pi,\rho\omega \longrightarrow \pi_1$
$\omega\omega,\rho\rho \longrightarrow \eta_1$
$\omega\omega,\rho\rho,\phi\omega \longrightarrow \eta'_1$
$\rho P \longrightarrow b_0$
$\omega P \longrightarrow h_0$
$\omega P, \phi P \longrightarrow h'_0$
$\omega\pi,\rho\eta,\rho P \longrightarrow b_2$
$\rho\pi,\omega\eta,\omega P \longrightarrow h_2$
$\rho\pi,\omega\eta,\phi P \longrightarrow h'_2$

$\rho\pi$ is charge-exchange only

Can couple to all the lightest exotic hybrid nonets through photo-production and VMD.

Linear polarization is a filter on the naturality of the exchanged particle.

Purpose of the Document

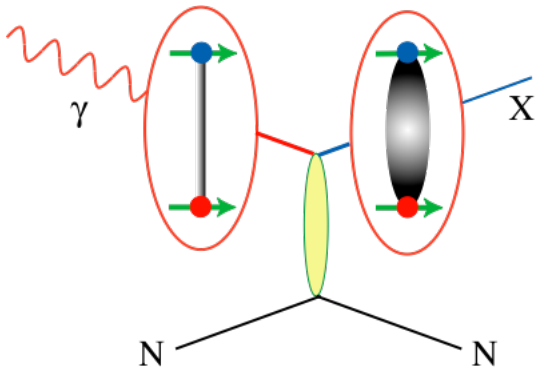
- Revisit the arguments that we make on production of exotic hybrids with an eye to being more quantitative.
- Revisit the potential decays of exotic hybrids with an eye to being more quantitative.

Decay Modes of Exotic Hybrids

$\pi_1 \rightarrow \pi\rho,\ \pi b_1,\ \pi f_1,\ \pi\eta',\ \eta a_1$
$\eta_1 \rightarrow \eta f_2,\ a_2\pi,\ \eta f_1,\ \eta\eta',\ \pi(1300)\pi,\ a_1\pi,$
$\eta_1' \rightarrow K^*K,\ K_1(1270)K,\ K_1(1410)K,\ \eta\eta'$

$b_2 \rightarrow \omega\pi,\ a_2\pi,\ \rho\eta,\ f_1\rho,\ a_1\pi,\ h_1\pi,\ b_1\eta$
$h_2 \rightarrow \rho\pi,\ b_1\pi,\ \omega\eta,\ f_1\omega$
$h'_2 \rightarrow K_1(1270)K,\ K_1(1410)K,\ K_2^*K,\ \phi\eta,\ f_1\phi$

$b_0 \rightarrow \pi(1300)\pi,\ h_1\pi,\ f_1\rho,\ b_1\eta$
$h_0 \rightarrow b_1\pi,\ h_1\eta$
$h'_0 \rightarrow K_1(1270)K,\ K(1460)K,\ h_1\eta$



Early Reach **With Statistics** **Hard**

Hybrid kaons do not have exotic QN's

Models suggest narrower states are in the spin-1 and spin-2 nonets, while the spin-0 nonets are broad.

Purpose of the Document

- Revisit the arguments that we make on production of exotic hybrids with an eye to being more quantitative.
- Revisit the potential decays of exotic hybrids with an eye to being more quantitative.
- Assume vector meson dominance and look at simplest exchange mechanisms (ρ, ω or ϕ beams).
- Insure conservation of strong quantum numbers I, J, P, C and G.
- Consider identical bosons, and isospin Clebsch-Gordan coefficients.

Mesons in the quark model

Normal Mesons

QNs				Names					
L	S	J^{PC}	(I^G)		(I^G)			(I)	
0	0	0^{-+}	(1^-)	π	(0^+)	η	η'	$(\frac{1}{2})$	**K**
0	1	1^{--}	(1^+)	ρ	(0^-)	ω	ϕ	$(\frac{1}{2})$	$\mathbf{K^*}$
1	0	1^{+-}	(1^+)	$\mathbf{b_1}$	(0^-)	$\mathbf{h_1}$	$\mathbf{h'_1}$	$(\frac{1}{2})$	$\mathbf{K_1}$
1	1	0^{++}	(1^-)	$\mathbf{a_0}$	(0^+)	$\mathbf{f_0}$	$\mathbf{f'_0}$	$(\frac{1}{2})$	$\mathbf{K_0^*}$
1	1	1^{++}	(1^-)	$\mathbf{a_1}$	(0^+)	$\mathbf{f_1}$	$\mathbf{f'_1}$	$(\frac{1}{2})$	$\mathbf{K_1}$
1	1	2^{++}	(1^-)	$\mathbf{a_2}$	(0^+)	$\mathbf{f_2}$	$\mathbf{f'_2}$	$(\frac{1}{2})$	$\mathbf{K_2^*}$
2	0	2^{-+}	(1^-)	π_2	(0^+)	η_2	η'_2	$(\frac{1}{2})$	$\mathbf{K_2}$
2	1	1^{--}	(1^+)	ρ_1	(0^-)	ω_1	ϕ_1	$(\frac{1}{2})$	$\mathbf{K_1^*}$
2	1	2^{--}	(1^+)	ρ_2	(0^-)	ω_2	ϕ_2	$(\frac{1}{2})$	$\mathbf{K_2}$
2	1	3^{--}	(1^+)	ρ_3	(0^-)	ω_3	ϕ_3	$(\frac{1}{2})$	$\mathbf{K_3^*}$

Identical Bosons must have even L

Production: $\rho^0\rho^0$, $\omega\omega$, $\phi\phi$

Exotic Hybrids

QNs			Names				
J^{PC}	(I^G)		(I^G)			(I)	
$\mathbf{1^{-+}}$	$(\mathbf{1^-})$	π_1	$(\mathbf{0^+})$	η_1	η'_1	$(\frac{1}{2})$	K_1^*
$\mathbf{0^{+-}}$	$(\mathbf{1^+})$	$\mathbf{b_0}$	$(\mathbf{0^-})$	$\mathbf{h_0}$	$\mathbf{h'_0}$	$(\frac{1}{2})$	K_0^*
$\mathbf{2^{+-}}$	$(\mathbf{1^+})$	$\mathbf{b_2}$	$(\mathbf{0^-})$	$\mathbf{h_2}$	$\mathbf{h'_2}$	$(\frac{1}{2})$	K_2^*

|0,0> -> |1,0> +|1,0>

~~|1,0> -> |1,0> + |1,0>~~

$$< 0\,0 \mid 1\,{+}1; 1\,{-}1 > = \sqrt{\frac{1}{3}}$$

$$< 0\,0 \mid 10; 10 > = -\sqrt{\frac{1}{3}}$$

$$< 0\,0 \mid 1\,{-}1; 1\,{+}1 > = \sqrt{\frac{1}{3}}.$$

$$< 1\,0 \mid 1\,{+}1; 1\,{-}1 > = \sqrt{\frac{1}{2}}$$

$$< 1\,0 \mid 10; 10 > = 0$$

$$< 1\,0 \mid 1\,{-}1; 1\,{+}1 > = \sqrt{\frac{1}{2}}.$$

Pion Exchange

π^0 Exchange

Incident	exchange	$(I)^G$	L		J^{PC}		Exotics
ρ	π^0	$(0)^-$	$L=0$	1^{+-}			
			$L=1$	0^{--}	1^{--}	2^{--}	
			$L=2$	1^{+-}	$\mathbf{2}^{+-}$	3^{+-}	h_2 , h_2'
ω,ϕ	π^0	$(1)^+$	$L=0$	1^{+-}			
			$L=1$	0^{--}	1^{--}	2^{--}	
			$L=2$	1^{+-}	$\mathbf{2}^{+-}$	3^{+-}	b_2^0

$\pi^\pm$ Exchange

Incident	exchange	$(I)^G$	L		J^P		Exotics
ρ	$\pi^\pm$	$(1)^-$	$L=0$	1^+			
			$L=1$	0^{--}	$\mathbf{1}^-$	2^-	$\pi_1^\pm$
			$L=2$	1^+	2^+	3^+	
ω,ϕ	$\pi^\pm$	$(1)^+$	$L=0$	1^+			
			$L=1$	0^{--}	1^-	2^-	
			$L=2$	1^+	$\mathbf{2}^+$	3^+	$b_2^\pm$

Eta/Eta-prime and Pomeron Exchange

η and η' Exchange

Incident	exchange	$(I)^G$	L		J^{PC}		Exotics
ρ	η, η'	$(1)^+$	$L=0$	1^{+-}			
			$L=1$	0^{--}	1^{--}	2^{--}	
			$L=2$	1^{+-}	$\mathbf{2}^{+-}$	3^{+-}	b_2^0
ω,ϕ	η, η'	$(0)^-$	$L=0$	1^{+-}			
			$L=1$	0^-	1^{--}	2^{--}	
			$L=2$	1^{+-}	$\mathbf{2}^{+-}$	3^{+-}	h_2 , h_2'

Pomeron Exchange

Incident	exchange	$(I)^G$	L		J^{PC}		Exotics
ρ	P	$(1)^+$	$L=0$	1^{--}			
			$L=1$	$\mathbf{0}^{+-}$	1^{+-}	$\mathbf{2}^{+-}$	b_0^0 , b_2^0
			$L=2$	1^{--}	2^{--}	3^{--}	
ω,ϕ	P	$(0)^-$	$L=0$	1^{--}			
			$L=1$	$\mathbf{0}^{+-}$	1^{+-}	$\mathbf{2}^{+-}$	h_0 , h_2 , h_0' , h_2'
			$L=2$	1^{--}	2^{--}	3^{--}	

Production of Exotic Hybrids

Exotic	Beam	Exchange	L
π_1^0	ρ^0	ω,ϕ	1
	ρ^0	h_1,h_1'	0, 2
	ω,ϕ	ρ^0	1
	ω,ϕ	b_1^0	0, 2
$\pi_1^\pm$	ρ^0	$\pi^\pm$	1
	ω,ϕ	$\rho^\pm$	1
	ω,ϕ	$b_1^\pm$	0, 2

Exotic	Beam	Exchange	L
η_1,η_1'	ρ^0	b_1^0	0, 2
	ω	ϕ	1
	ϕ	ω	1
	ω,ϕ	h_1, h_1'	0, 2

Exotic	Beam	Exchange	L
b_2^0	ρ^0	η, η'	2
	ρ^0	$\mathcal{P}$	1
	ω, ϕ	π^0	2
$b_2^\pm$	ρ^0	$\rho^\pm$	0, 2
	ω,ϕ	$\pi^\pm$	2

Exotic	Beam	Exchange	L
h_2, h_2'	ω, ϕ	η, η'	2
	ω, ϕ	$\mathcal{P}$	1

Exotic	Beam	Exchange	L
b_0^0	ρ^0	$\mathcal{P}$	1
$b_0^\pm$	ρ^0	$\rho^\pm$	0, 2
	ρ^0	$b_1^\pm$	1

Exotic	Beam	Exchange	L
h_0, h_0'	ω, ϕ	$\mathcal{P}$	1

Decays of Exotic Hybrids

π_1^0 Decays

Exotic	$(I)^G J^{PC}$	Daughters		L	Final States	
π_1^0	$(1)^-1^{-+}$	$\rho^\pm$	$\pi^\mp$	1	$\pi^+\pi^-\pi^0$	
		η'	π^0	1	$\eta\pi^+\pi^-\pi^0$	$\eta\pi^0\pi^0\pi^0$
		f_1	π^0	0	$\eta\pi^+\pi^-\pi^0$	$\eta\pi^0\pi^0\pi^0$
		$b_1^\pm$	$\pi^\mp$	1	$\omega\pi^+\pi^-$	
		ρ^0	ω	1	$\omega\pi^+\pi^-$	
		a_1^0	η	1	$\eta\pi^+\pi^-\pi^0$	
		b_1^0	ω	0	$\omega\omega\pi^0$	

$\pi_1^\pm$ Decays

Exotic	$(I)^G J^P$	Daughters		L	Final States	
$\pi_1^\pm$	$(1)^-1^-$	$\rho^\pm$	π^0	1	$\pi^\pm\pi^0\pi^0$	
		ρ^0	$\pi^\pm$	1	$\pi^\pm\pi^+\pi^-$	
		η'	$\pi^\pm$	1	$\eta\pi^+\pi^-\pi^\pm$	$\eta\pi^0\pi^0\pi^\pm$
		f_1	$\pi^\pm$	0	$\eta\pi^+\pi^-\pi^\pm$	$\eta\pi^0\pi^0\pi^\pm$
		$b_1^\pm$	π^0	1	$\omega\pi^\pm\pi^0$	
		b_1^0	$\pi^\pm$	1	$\omega\pi^0\pi^\pm$	
		$b_1^\pm$	ω	0	$\omega\omega\pi^\pm$	
		$\rho^\pm$	ω	1	$\omega\pi^\pm\pi^0$	
		$a_1^\pm$	η	0	$\eta\pi^\pm\pi^+\pi^-$	$\eta\pi^\pm\pi^0\pi^0$

η_1 and η_1' Decays

Exotic	$(I)^G J^{PC}$	Daughters		L	Final States		
	$(0)^+1^{-+}$	η'	η	1	$\eta\eta\pi^+\pi^-$	$\eta\eta\pi^0\pi^0$	
		f_1	η	0	$\eta\eta\pi^+\pi^-$	$\eta\eta\pi^0\pi^0$	
		f_2	η	2	$\eta\pi^+\pi^-$	$\eta\pi^0\pi^0$	
		$a_2^\pm$	$\pi^\mp$	2	$\eta\pi^+\pi^-$	$\pi^+\pi^-\pi^+\pi^-$	$\pi^+\pi^-\pi^0\pi^0$
		a_2^0	π^0	2	$\eta\pi^0\pi^0$	$\pi^+\pi^-\pi^0\pi^0$	
		a_1^0	π^0	0	$\eta\pi^0\pi^0$	$\pi^+\pi^-\pi^0\pi^0$	
		b_1^0	ρ^0	0	$\omega\pi^+\pi^-\pi^0$		
	$(0)^+1^{-+}$	ω	ϕ	1	$\omega\phi$		
		$(K^*)^\pm$	$K^\mp$	1	$K^+K^-\pi^0$		
		$(K^*)^0$	K_S	0	$K^+K_S\pi^-$	$K^-K_S\pi^+$	
		$K_1^\pm$	$K^\mp$	0	$K^+K^-\pi^+\pi^-$		
		K_1^0	K_S	1	$K^+K_S\pi^-\pi^0$	$K^-K_S\pi^+\pi^0$	

Decays of Exotic Hybrids

b_2^0 Decays

Exotic	$(I)^G J^{PC}$	Daughters		L	Final States		
b_2^0	$(1)^+2^{+-}$	ω	π^0	2	$\omega\pi^0$		
		ρ^0	η	2	$\eta\pi^+\pi^-$		
		$a_2^\pm$	$\pi^\mp$	1	$\eta\pi^+\pi^-$	$\pi^+\pi^-\pi^+\pi^-$	$\pi^+\pi^-\pi^0\pi^0$
		b_1^0	η	1	$\omega\eta\pi^0$		
		f_1	ρ^0	1	$\eta\pi^+\pi^-\pi^+\pi^-$	$\eta\pi^+\pi^-\pi^0\pi^0$	
		$a_1^\pm$	$\pi^\mp$	1	$\pi^+\pi^-\pi^+\pi^-$	$\pi^+\pi^-\pi^0\pi^0$	

$b_2^\pm$ Decays

Exotic	$(I)^G J^P$	Daughters		L	Final States		
$b_2^\pm$	$(1)^+2^+$	ω	$\pi^\pm$	2	$\omega\pi^\pm$		
		$\rho^\pm$	η	2	$\eta\pi^\pm\pi^0$		
		$a_2^\pm$	π^0	1	$\eta\pi^\pm\pi^0$	$\pi^\pm\pi^+\pi^-\pi^0$	$\pi^\pm\pi^0\pi^0\pi^0$
		a_2^0	$\pi^\pm$	1	$\pi^\pm\pi^+\pi^-\pi^0$		
		$b_1^\pm$	η	1	$\omega\eta\pi^\pm$		
		b_1^0	$\rho^\pm$	1	$\omega\pi^0\pi^0\pi^\pm$		
		$b_1^\pm$	ρ^0	1	$\omega\pi^+\pi^-\pi^\pm$		
		f_1	$\rho^\pm$	1	$\eta\pi^+\pi^-\pi^0\pi^\pm$	$\eta\pi^0\pi^0\pi^0\pi^\pm$	
		$a_1^\pm$	π^0	1	$\pi^\pm\pi^+\pi^-\pi^0$	$\pi^\pm\pi^0\pi^0\pi^0$	
		a_1^0	$\pi^\mp$	1	$\pi^\pm\pi^+\pi^-\pi^0$		

h_2 and h_2' Decays

Exotic	$(I)^G J^{PC}$	Daughters		L	Final States	
h_2	$(0)^-2^{+-}$	ρ^0	π^0	2	$\pi^+\pi^-\pi^0$	
		ω	η	2	$\omega\eta$	
		$b_1^\pm$	$\pi^\mp$	1	$\omega\pi^+\pi^-$	
		b_1^0	π^0	1	$\omega\pi^0\pi^0$	
		f_1	ω	1	$\omega\eta\pi^+\pi^-$	$\omega\eta\pi^0\pi^0$
h_2'	$(0)^-2^{+-}$	ϕ	η	2	$\phi\eta$	
		f_1	ϕ	1	$\phi\eta\pi^+\pi^-$	$\phi\eta\pi^0\pi^0$
		$K_1^\pm$	$K^\mp$	1	$K^+K^-\pi^+\pi^-$	
		K_1^0	K_S	2	$K^+K_S\pi^-$	$K^-K_S\pi^+$
		$(K_2^*)^\pm$	$K^\mp$	1	$K^+K^-\pi^0$	$K^+K^-\pi^+\pi^-$
		$(K_2^*)^0$	K_S	0, 2	$K^\pm K_S\pi^\mp$	$K^\pm K_S\pi^\mp\pi^0$

Decays of Exotic Hybrids

b_0^0 Decays

Exotic	$(I)^G J^{PC}$	Daughters		L	Final States	
b_0^0	$(1)^+0^{+-}$	f_1	ρ^0	1	$\eta\pi^+\pi^-\pi^+\pi^-$	$\eta\pi^+\pi^-\pi^0\pi^0$
		b_1^0	η	1	$\omega\eta\pi^0$	
		h_1	π^0	1	$\pi^+\pi^-\pi^0\pi^0$	

$b_0^\pm$ Decays

Exotic	$(I)^G J^P$	Daughters		L	Final States	
$b_0^\pm$	$(1)^+0^+$	f_1	$\rho^\pm$	1	$\eta\pi^+\pi^-\pi^0\pi^\pm$	$\eta\pi^0\pi^0\pi^0\pi^\pm$
		$b_1^\pm$	η	1	$\omega\eta\pi^\pm$	
		b_1^0	$\rho^\pm$	1	$\omega\pi^0\pi^0\pi^\pm$	
		$b_1^\pm$	ρ^0	1	$\omega\pi^+\pi^-\pi^\pm$	
		h_1	$\pi^\pm$	1	$\pi^+\pi^-\pi^0\pi^\pm$	

h_0 and h_0' Decays

$(I)^G J^{PC}$	Daughters		L	Final States	
$(0)^-0^{+-}$	$b_1^\pm$	$\pi^\mp$	1	$\omega\pi^+\pi^-$	
	b_1^0	π^0	1	$\omega\pi^0\pi^0$	
	h_1	η	1	$\eta\pi^+\pi^-\pi^0$	
$(0)^-0^{+-}$	$K_1^\pm$	$K^\mp$	1	$K^+K^-\pi^+\pi^-$	
	$K(1460)^\pm$	$K^\mp$	0	$K^+K^-\pi^+\pi^-$	$K^+K^-\pi^0\pi^0$

- This document looks at the simplest production mechanisms, including both natural and unnatural parity exchange.
  - One could extend to a_0, a_1 and a_2 exchange if that is deemed interesting.
  - Photoproduction of charged and neutral isospin 1 states can be quite different. It is important to look for both of charged and neutral states.
- I have looked at the simplest decays, others are possible, but tend to lead to even more complicated final states.