

# Exotic hadrons in s-wave chiral dynamics



**Tetsuo Hyodo<sup>a</sup>**

**D. Jido<sup>a</sup>, and A. Hosaka<sup>b</sup>**

*YITP, Kyoto<sup>a</sup>    RCNP, Osaka<sup>b</sup>*

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# Exotic hadrons in s-wave chiral dynamics



**Exotic hadrons**



**Status of the pentaquark  $\Theta^+$**



**Recent work**

**Tetsuo Hyodo<sup>a</sup>**

**D. Jido<sup>a</sup>, and A. Hosaka<sup>b</sup>**

*YITP, Kyoto<sup>a</sup>    RCNP, Osaka<sup>b</sup>*

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## Exotic hadrons

**Exotic hadrons : states other than  $q\bar{q}$ ,  $qqq$ .**

**--> Neither QCD nor effective approaches  
(quark model,...) forbid such states.**

**Experimentally, (almost?) completely absent**

**--> highly non-trivial fact**



# Exotic hadrons

## Exotic hadrons : states other than $q\bar{q}$ , $qqq$ .

$p$	$P_{11}$	****	$\Delta(1232)$	$P_{33}$	****	$\Lambda$	$P_{01}$	****	$\Sigma^+$	$P_{11}$	****	$\Xi^0$	$P_{11}$	****	LIGHT UNFLAVORED ( $S = C = B = 0$ )		STRANGE ( $S = \pm 1, C = B = 0$ )		BOTTOM ( $B = \pm 1$ )	
$n$	$P_{11}$	****	$\Delta(1600)$	$P_{33}$	***	$\Lambda(1405)$	$S_{01}$	****	$\Sigma^0$	$P_{11}$	****	$\Xi^-$	$P_{11}$	****	$\rho^0(\rho^C)$	$\rho^0(\rho^C)$	$K^{\pm}$	$K^0$	$B^{\pm}$	$B^0$
$N(1440)$	$P_{11}$	****	$\Delta(1620)$	$S_{31}$	****	$\Lambda(1520)$	$D_{03}$	****	$\Sigma^-$	$P_{11}$	****	$\Xi(1530)$	$P_{13}$	****	$\omega(782)$	$\omega(1710)$	$\rho(1690)$	$\rho(1700)$	$B^{\pm}/B^0$ ADMIXTURE	$B^0$
$N(1520)$	$D_{13}$	****	$\Delta(1700)$	$D_{33}$	****	$\Lambda(1600)$	$P_{01}$	***	$\Sigma(1385)$	$P_{13}$	****	$\Xi(1620)$	*	*	$\eta(782)$	$\eta(1710)$	$\rho(1700)$	$\rho(1700)$	$B^{\pm}/B^0/B_s^{\pm}/b$ -baryon ADMIXTURE	$B^0$
$N(1535)$	$S_{11}$	****	$\Delta(1750)$	$P_{31}$	*	$\Lambda(1670)$	$S_{01}$	****	$\Sigma(1480)$	*	*	$\Xi(1690)$	***	*	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$V_{cb}$ and $V_{cb}$ CKM Matrix Elements	$B^0$
$N(1650)$	$S_{11}$	****	$\Delta(1900)$	$S_{31}$	**	$\Lambda(1690)$	$D_{03}$	****	$\Sigma(1560)$	**	**	$\Xi(1820)$	$D_{13}$	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
$N(1675)$	$D_{15}$	****	$\Delta(1905)$	$F_{35}$	****	$\Lambda(1800)$	$S_{01}$	***	$\Sigma(1580)$	$D_{13}$	*	$\Xi(1950)$	*	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
$N(1680)$	$F_{15}$	****	$\Delta(1910)$	$P_{31}$	****	$\Lambda(1810)$	$P_{01}$	***	$\Sigma(1620)$	$S_{11}$	**	$\Xi(2030)$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
$N(1700)$	$D_{13}$	***	$\Delta(1920)$	$P_{33}$	***	$\Lambda(1820)$	$F_{05}$	****	$\Sigma(1660)$	$P_{11}$	***	$\Xi(2120)$	*	*	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
$N(1710)$	$P_{11}$	***	$\Delta(1930)$	$D_{35}$	***	$\Lambda(1830)$	$D_{05}$	****	$\Sigma(1670)$	$D_{13}$	****	$\Xi(2250)$	**	**	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
$N(1720)$	$P_{13}$	****	$\Delta(1940)$	$D_{33}$	*	$\Lambda(1890)$	$P_{03}$	****	$\Sigma(1690)$	*	**	$\Xi(2370)$	**	**	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
$N(1900)$	$P_{13}$	**	$\Delta(1950)$	$F_{37}$	****	$\Lambda(2000)$	*	*	$\Sigma(1750)$	$S_{11}$	***	$\Xi(2500)$	*	*	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
$N(1990)$	$F_{17}$	**	$\Delta(2000)$	$F_{35}$	**	$\Lambda(2020)$	$F_{07}$	*	$\Sigma(1770)$	$P_{11}$	*	$\Omega^-$	****	****	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
$N(2000)$	$F_{15}$	**	$\Delta(2150)$	$S_{31}$	*	$\Lambda(2100)$	$G_{07}$	****	$\Sigma(1775)$	$D_{15}$	****	$\Omega(2250)$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
$N(2080)$	$D_{13}$	**	$\Delta(2200)$	$G_{37}$	*	$\Lambda(2110)$	$F_{05}$	***	$\Sigma(1840)$	$P_{13}$	*	$\Omega(2380)$	**	**	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
$N(2090)$	$S_{11}$	*	$\Delta(2300)$	$H_{39}$	**	$\Lambda(2325)$	$D_{03}$	*	$\Sigma(1880)$	$P_{11}$	**	$\Omega(2470)$	**	**	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
$N(2100)$	$P_{11}$	*	$\Delta(2350)$	$D_{35}$	*	$\Lambda(2350)$	$H_{09}$	***	$\Sigma(1915)$	$F_{15}$	****	$\Omega(2470)$	**	**	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
$N(2190)$	$G_{17}$	****	$\Delta(2390)$	$F_{37}$	*	$\Lambda(2585)$	**	**	$\Sigma(1940)$	$D_{13}$	***	$\Lambda_c^+$	****	****	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
$N(2200)$	$D_{15}$	**	$\Delta(2400)$	$G_{39}$	**				$\Sigma(2000)$	$S_{11}$	*	$\Lambda_c^+$	****	****	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
$N(2220)$	$H_{19}$	****	$\Delta(2420)$	$H_{3,11}$	****				$\Sigma(2030)$	$F_{17}$	****	$\Lambda_c(2593)^+$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
$N(2250)$	$G_{19}$	****	$\Delta(2470)$	$H_{3,11}$	****				$\Sigma(2070)$	$F_{15}$	**	$\Lambda_c(2625)^+$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
$N(2600)$	$I_{1,11}$	***	$\Delta(2750)$	$I_{3,13}$	**				$\Sigma(2080)$	$P_{13}$	**	$\Lambda_c(2765)^+$	*	*	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
$N(2700)$	$K_{1,13}$	**	$\Delta(2950)$	$K_{3,15}$	**				$\Sigma(2100)$	$G_{17}$	*	$\Lambda_c(2880)^+$	**	**	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
			$\Theta(1540)^+$	*	*				$\Sigma(2250)$		***	$\Sigma_c(2455)$	****	****	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
									$\Sigma(2455)$		**	$\Sigma_c(2520)$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
									$\Sigma(2620)$		**	$\Sigma_c(2800)$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
									$\Sigma(3000)$		*	$\Xi_c^+$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
									$\Sigma(3170)$		*	$\Xi_c^0$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^+$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^0$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^+$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^0$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^+$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^0$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^+$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^0$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^+$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^0$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^+$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^0$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^+$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^0$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^+$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^0$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^+$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^0$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^+$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^0$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^+$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^0$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^+$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^0$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^+$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^0$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^+$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^0$	***	***	$\eta(958)$	$\eta(1760)$	$\rho(1700)$	$\rho(1700)$	$B_s^{\pm}$	$B^0$
												$\Xi_c^+$	***	***	$\eta(958)$	$\eta(1$				



# Exotic hadrons

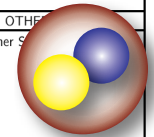
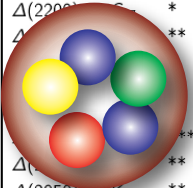
## Exotic hadrons : states other than $q\bar{q}$ , $qqq$ .

$p$	$P_{11}$	****	$\Delta(1232)$	$P_{33}$	****	$\Lambda$	$P_{01}$	****	$\Sigma^+$	$P_{11}$	****	$\Xi^0$	$P_{11}$	****
$n$	$P_{11}$	****	$\Delta(1600)$	$S_{33}$	***	$\Lambda(1405)$	$S_{01}$	****	$\Sigma^0$	$P_{11}$	****	$\Xi^-$	$P_{11}$	****
$N(1440)$	$P_{11}$	****	$\Delta(1620)$	$S_{31}$	****	$\Lambda(1520)$	$D_{03}$	****	$\Sigma^-$	$P_{11}$	****	$\Xi(1530)$	$P_{13}$	****
$N(1520)$	$D_{13}$	****	$\Delta(1700)$	$D_{33}$	****	$\Lambda(1600)$	$P_{01}$	***	$\Sigma(1385)$	$P_{13}$	****	$\Xi(1620)$	*	
$N(1535)$	$S_{11}$	****	$\Delta(1750)$	$P_{31}$	*	$\Lambda(1670)$	$S_{01}$	****	$\Sigma(1480)$	*		$\Xi(1690)$	***	
$N(1650)$	$S_{11}$	****	$\Delta(1900)$	$S_{31}$	**	$\Lambda(1690)$	$D_{03}$	****	$\Sigma(1560)$	**		$\Xi(1820)$	$D_{13}$	***
$N(1675)$	$D_{15}$	****	$\Delta(1905)$	$F_{35}$	****	$\Lambda(1800)$	$S_{01}$	***	$\Sigma(1580)$	$D_{13}$	*	$\Xi(1950)$	***	
$N(1680)$	$F_{15}$	****	$\Delta(1910)$	$P_{31}$	****	$\Lambda(1810)$	$P_{01}$	***	$\Sigma(1620)$	$S_{11}$	**	$\Xi(2030)$	***	
$N(1700)$	$D_{13}$	***	$\Delta(1920)$	$P_{33}$	***	$\Lambda(1820)$	$F_{05}$	****	$\Sigma(1660)$	$P_{11}$	***	$\Xi(2120)$	*	
$N(1710)$	$P_{11}$	***	$\Delta(1930)$	$D_{35}$	***	$\Lambda(1830)$	$D_{05}$	****	$\Sigma(1670)$	$D_{13}$	****	$\Xi(2250)$	**	
$N(1720)$	$P_{13}$	****	$\Delta(1940)$	$D_{33}$	*	$\Lambda(1890)$	$P_{03}$	****	$\Sigma(1690)$	*		$\Xi(2370)$	**	
$N(1900)$	$P_{13}$	**	$\Delta(1950)$	$F_{37}$	****	$\Lambda(2000)$	*		$\Sigma(1750)$	$S_{11}$	***	$\Xi(2500)$	*	
$N(1990)$	$F_{17}$	**	$\Delta(2000)$	$F_{35}$	**	$\Lambda(2020)$	$F_{07}$	*	$\Sigma(1770)$	$P_{11}$	*	$\Omega^-$	****	
$N(2000)$	$F_{15}$	**	$\Delta(2150)$	$S_{31}$	*	$\Lambda(2100)$	$G_{07}$	****	$\Sigma(1775)$	$D_{15}$	****	$\Omega(2250)^-$	***	
$N(2080)$	$D_{13}$	**	$\Delta(2200)$	*		$\Lambda(2110)$	$F_{05}$	***	$\Sigma(1840)$	$P_{13}$	*	$\Omega(2380)^-$	**	
$N(2090)$	$S_{11}$	*	$\Delta(2200)$	**		$\Lambda(2325)$	$D_{03}$	*	$\Sigma(1880)$	$P_{11}$	**	$\Omega(2470)^-$	**	
$N(2100)$	$P_{11}$	*	$\Delta(2200)$	**		$\Lambda(2350)$	$H_{09}$	***	$\Sigma(1915)$	$F_{15}$	****	$\Lambda_c^+$	****	
$N(2190)$	$G_{17}$	****	$\Delta(2200)$	**		$\Lambda(2585)$	**		$\Sigma(1940)$	$D_{13}$	***	$\Lambda_c(2593)^+$	***	
$N(2200)$	$D_{15}$	**	$\Delta(2200)$	**					$\Sigma(2000)$	$S_{11}$	*	$\Lambda_c(2625)^+$	***	
$N(2220)$	$H_{19}$	****	$\Delta(2200)$	**					$\Sigma(2030)$	$F_{17}$	****	$\Lambda_c(2765)^+$	***	
$N(2250)$	$G_{19}$	****	$\Delta(2200)$	**					$\Sigma(2070)$	$F_{15}$	***	$\Lambda_c(2880)^+$	**	
$N(2600)$	$I_{1,11}$	***	$\Delta(2950)$	$K_{3,15}$	**				$\Sigma(2080)$	$P_{13}$	**	$\Sigma_c(2455)$	****	
$N(2700)$	$K_{1,13}$	**	$\Theta(1540)^+$	*					$\Sigma(2100)$	$G_{17}$	*	$\Sigma_c(2520)$	***	
									$\Sigma(2250)$		***	$\Sigma_c(2800)$	***	
									$\Sigma(2455)$		**	$\Sigma_c(2815)$	***	
									$\Sigma(2620)$		**	$\Omega_c^0$	***	
									$\Sigma(3000)$		*	$\Xi_c^+$	***	
									$\Sigma(3170)$		*	$\Xi_c^0$	***	
									$\Xi_c^+$		***	$\Xi_c^+$	***	
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									$\Xi_c^+$		***	$\Xi_c^+$	***	
									$\Xi_c^0$		***	$\Xi_c^0$	***	
									$\Xi_c^+$		***	$\Xi_c^+$	***	
									$\Xi_c^0$		***	$\Xi_c^0$	***	
									$\Xi_c^+$		***	$\Xi_c^+$	***	
									$\Xi_c^0$		***	$\Xi_c^0$	***	
									$\Xi_c^+$		***	$\Xi_c^+$	***	
									$\Xi_c^0$		***	$\Xi_c^0$	***	
									$\Xi_c^+$		***	$\Xi_c^+$	***	
									$\Xi_c^0$		***	$\Xi_c^0$	***	

# Exotic hadrons

## Exotic hadrons : states other than $q\bar{q}$ , $qqq$ .

Baryons				Mesons			
$J^P$	State	Count	Notes	$J^P$	State	Count	Notes
$1/2^+$	$\Theta(1540)^+$	1	Exotic baryon	$0^-$	$\eta(1770)$	1	Light unflavored meson
		286	Total baryons			159	Total mesons



127 baryons

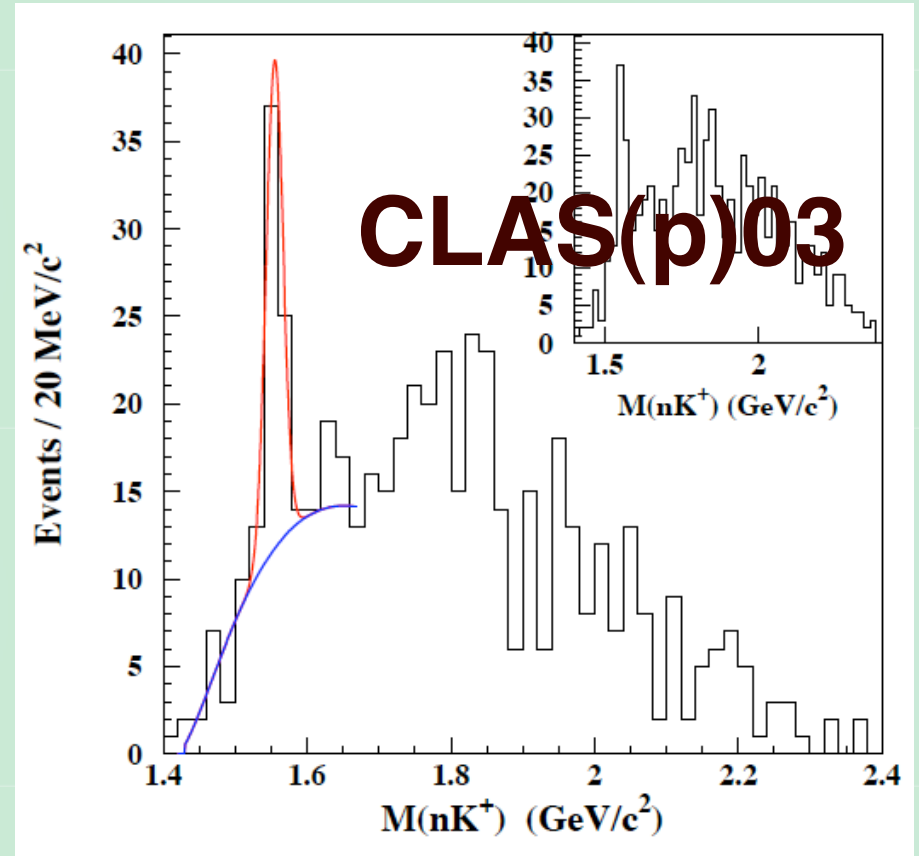
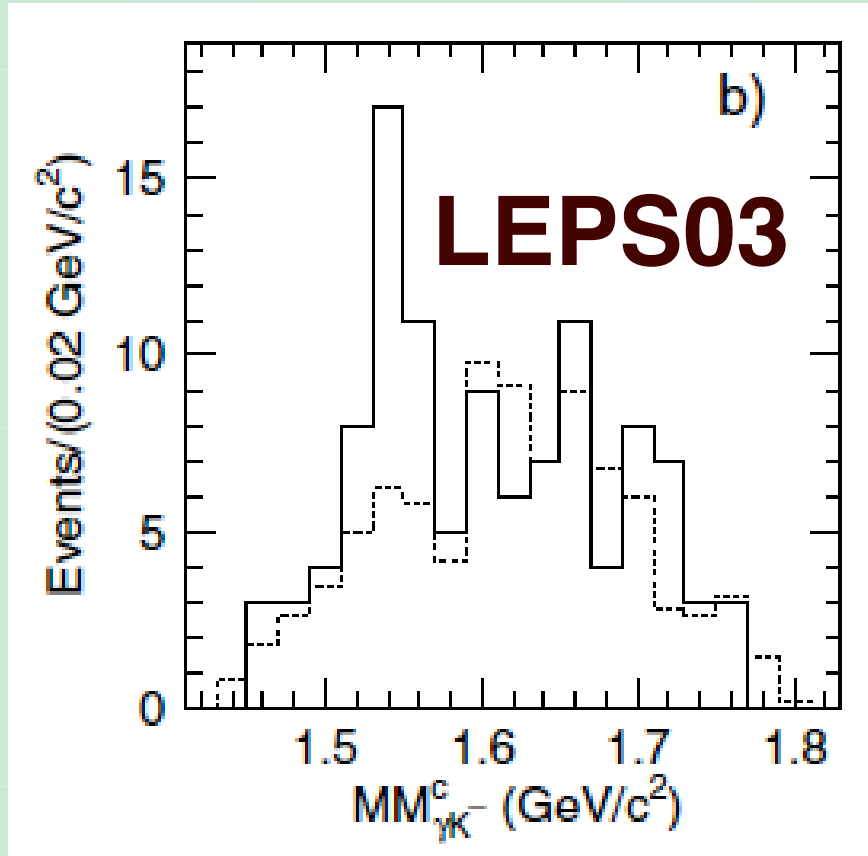
159 mesons

--> Examine existence of exotic hadrons in flavor SU(3) limit.



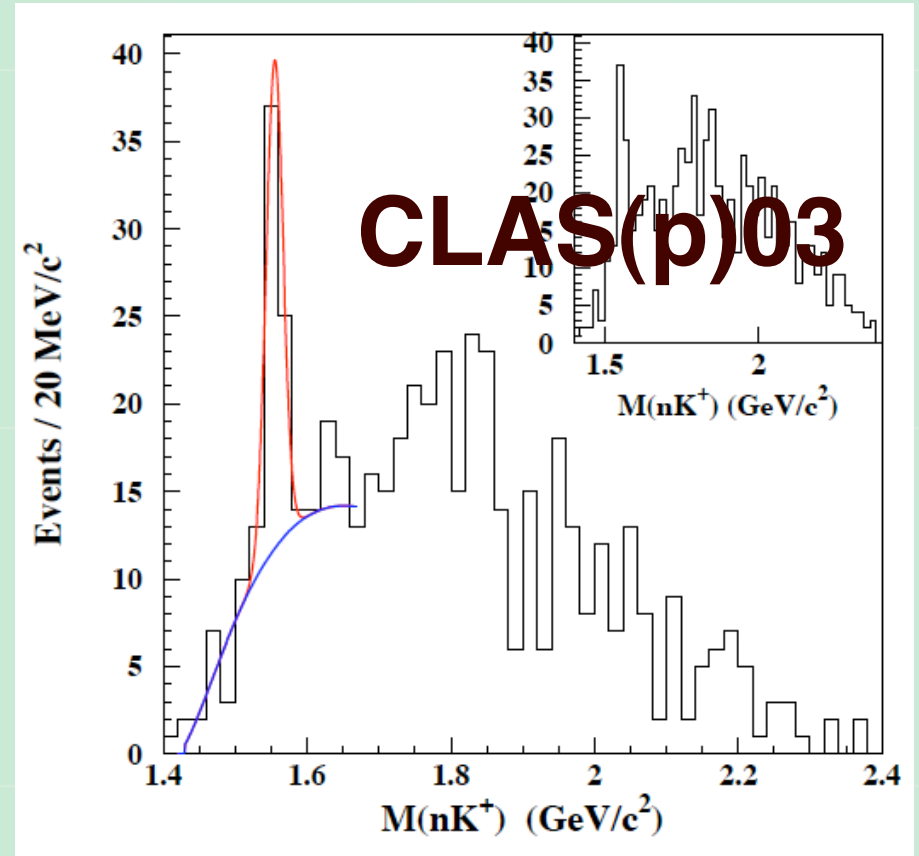
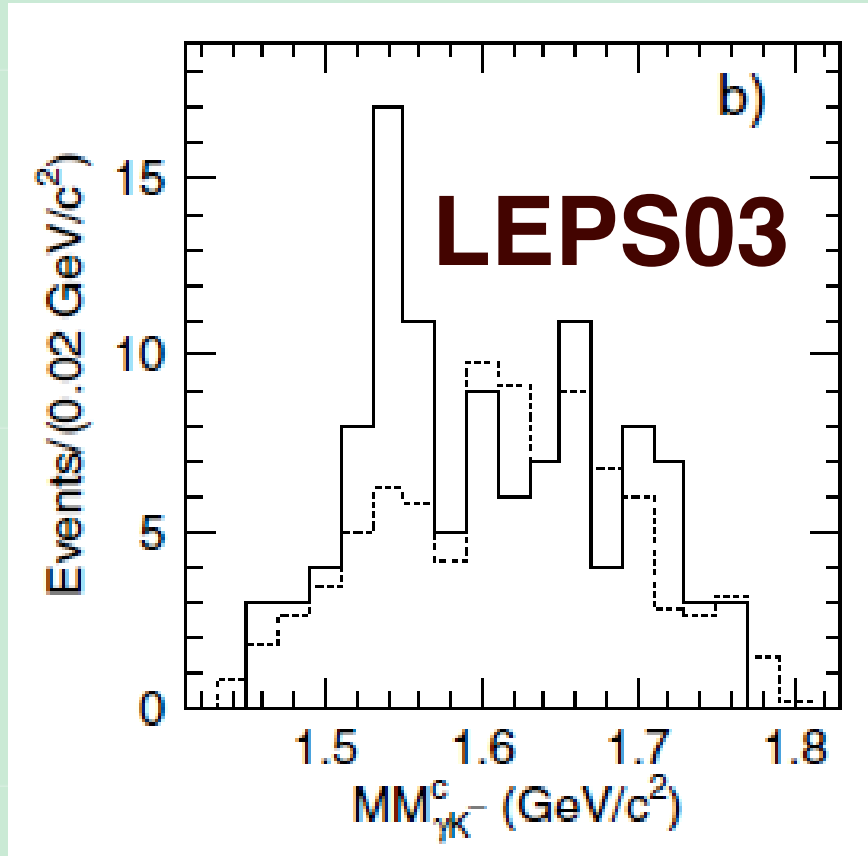
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2003 ~ 2004 : 6 positive results



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Citation: S. Eidelman *et al.* (Particle Data Group), Phys. Lett. B 592, 1 (2004) (URL: <http://pdg.lbl.gov>)

$\Theta(1540)^+$

$I(J^P) = 0(?^?)$  Status: \*\*\*

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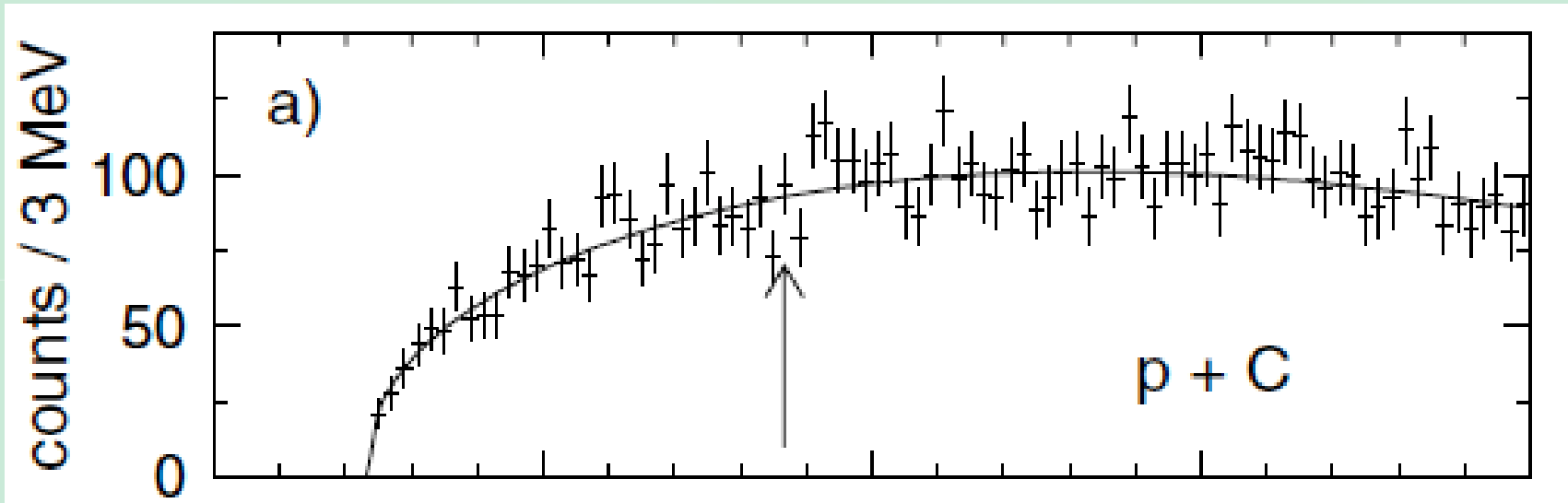
Citation: S. Eidelman *et al.* (Particle Data Group), Phys. Lett. B **592**, 1 (2004) (URL: <http://pdg.lbl.gov>)

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~ 2005 : **12 positive** results,  
**7 negative** (high-energy inclusive).



**HERA-B**  
**920 GeV p beam**

**\* limited number of resonances  
are observed in high energy exp.**

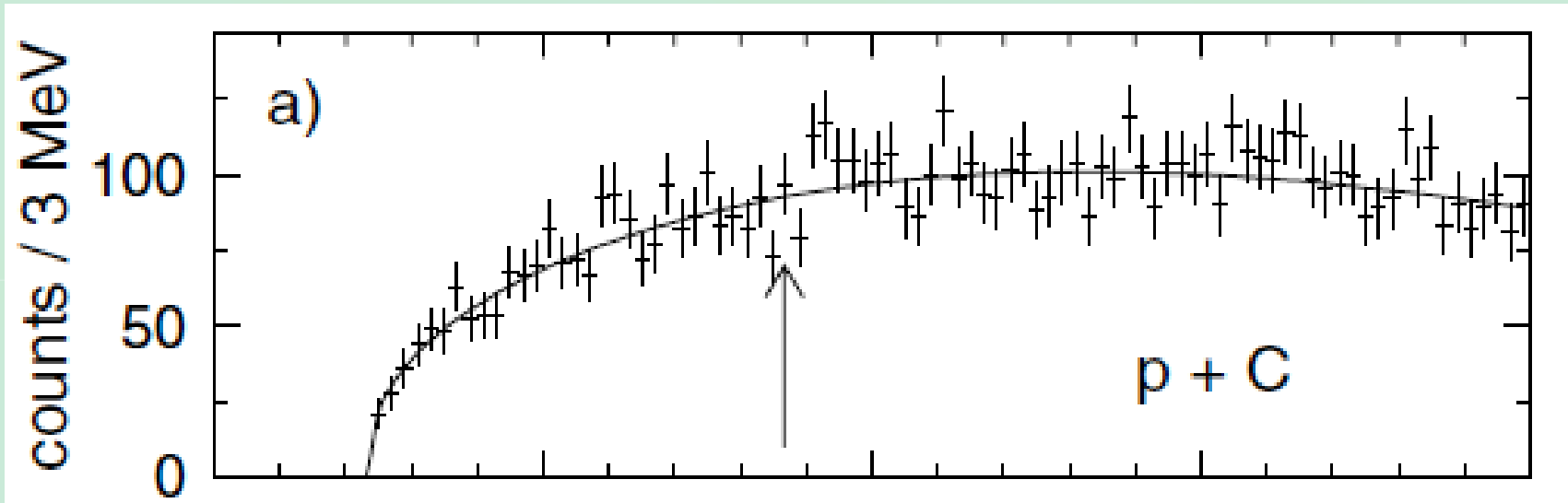
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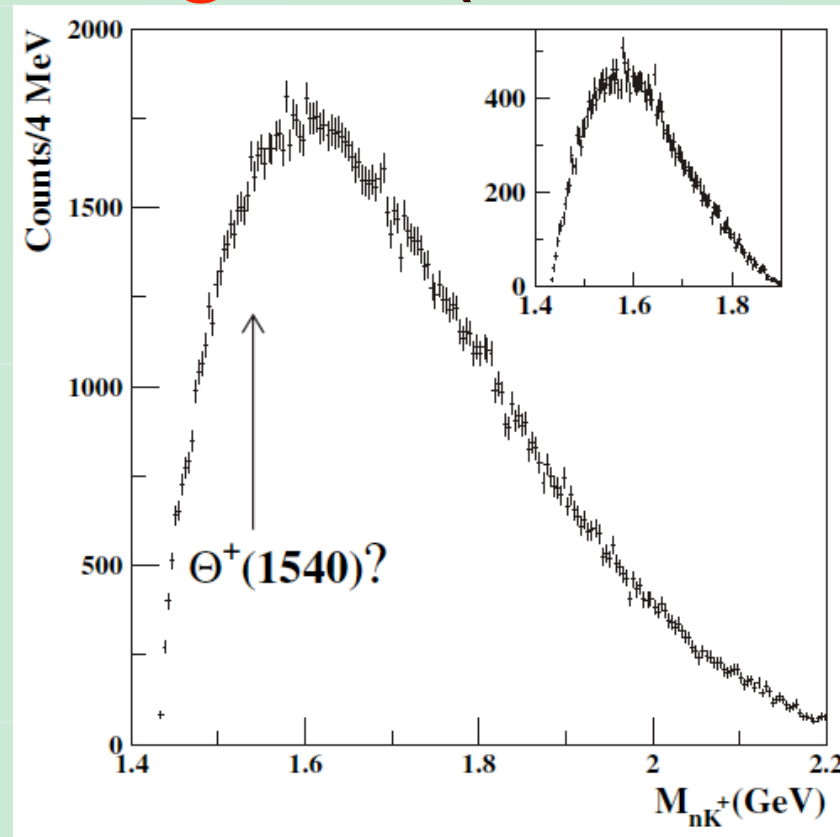
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**CLAS06**

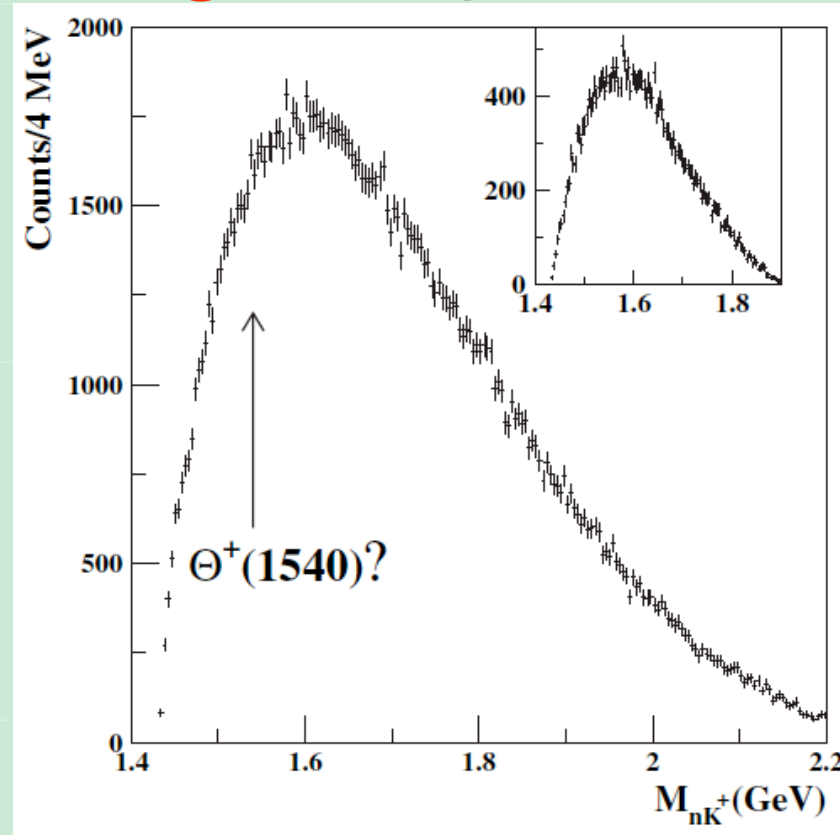
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**CLAS06**

Citation: W.-M. Yao *et al.* (Particle Data Group), J. Phys. G **33**, 1 (2006) (URL: <http://pdg.lbl.gov>)

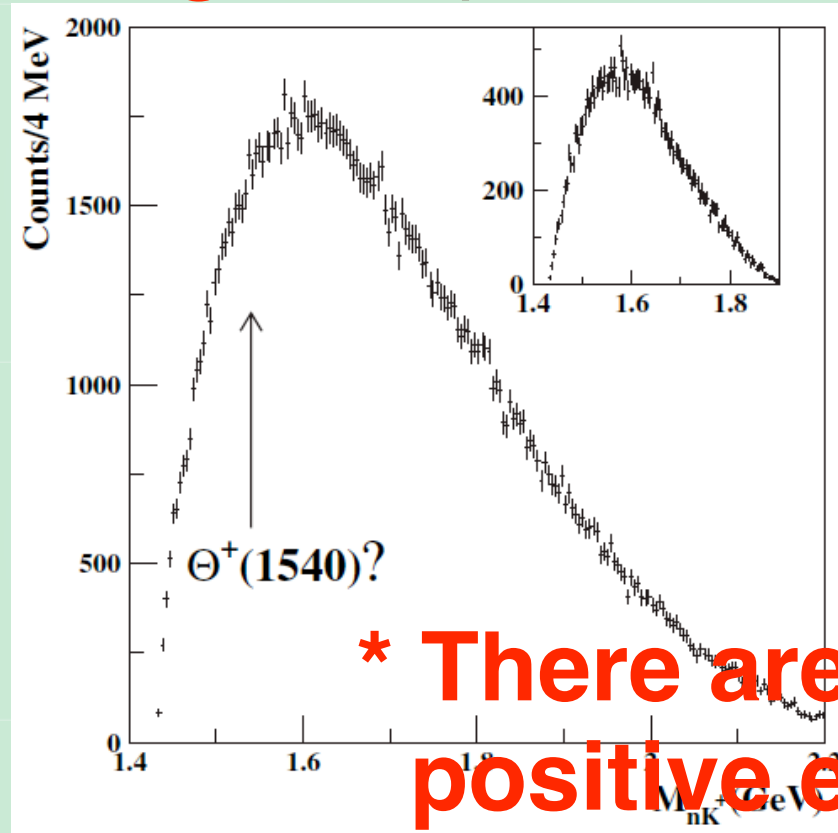
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# Status of pentaquark $\Theta^+$

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**CLAS06**

**\* There are also positive evidences!**

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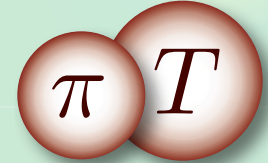
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# Exotic hadrons in s-wave chiral dynamics

T. Hyodo, D. Jido, A. Hosaka, hep-ph/0609014, Phys. Rev. Lett., in press

## Hadron-NG boson bound state



### Chiral symmetry

### s-wave low energy interaction

$$V_{\alpha} = -\frac{\omega}{2f^2} C_{\alpha,T}$$

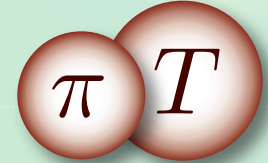
### Scattering theory

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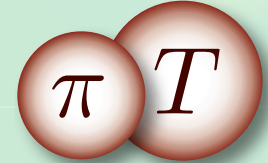
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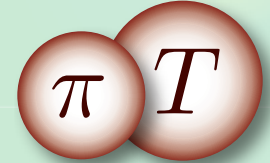
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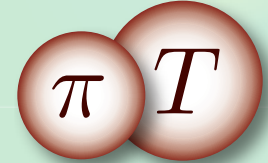
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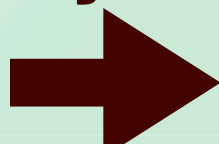
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**physical values :  $C_{\text{exotic}} < C_{\text{crit}}$**



**No exotic state exists.**