The JPC=1^{-+} Exotic Spectrum from BNL/E852

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E852: Multi-Particle Spectrometer 18 GeV/c π^- on LH_2 target

Data Runs: 1994, 1995, 1997, 1998 Cerenkov detector for π/K separation

Review: $\pi_1(1400) \rightarrow \eta\pi^-$ $\pi_1(1600) \rightarrow \rho\pi^-, \eta'\pi^-$

New results from $\pi^+\pi^-\pi^-$, $\eta\pi^+\pi^-\pi^-$, $\omega\pi^+\pi^0$, $\eta\eta\pi$

$$\pi_1(1600) \rightarrow f_1(1285)\pi^-, b_1(1235)\pi$$

$$\pi_1(2000) \rightarrow f_1(1285)\pi^-, b_1(1235)\pi$$

$q\bar{q}$ Quantum Numbers

$\vec{J} = \vec{L} + \vec{S}$ $\quad L = 0,1,2... \quad S = 0,1$

Parity: $-1^{(L+1)}$

- Dirac Fermions
- Spatial Wave Function

Charge Conjugation: The operation: $f_e \times S_e \times R(\pi) \times C = 1$

f_e : *Fermion exchange* $= -1$

S_e : *Spin exchange* $= -1^{(S+1)}$

$R(\pi)$: *Rotation of* π *radians* $= -1^{L}$

$$C = -1^{(L+S)}$$

Isospin: $I = 0,1$

G-Parity: $G = C\, e^{i\pi I_y} = C(-1^{I})$

Forbidden J^{PC}: $0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, 3^{-+}$ ...

Light Quark Hybrid Mass and Decays

Light Quark $J^{PC}=1^{-+}$ Lattice Mass

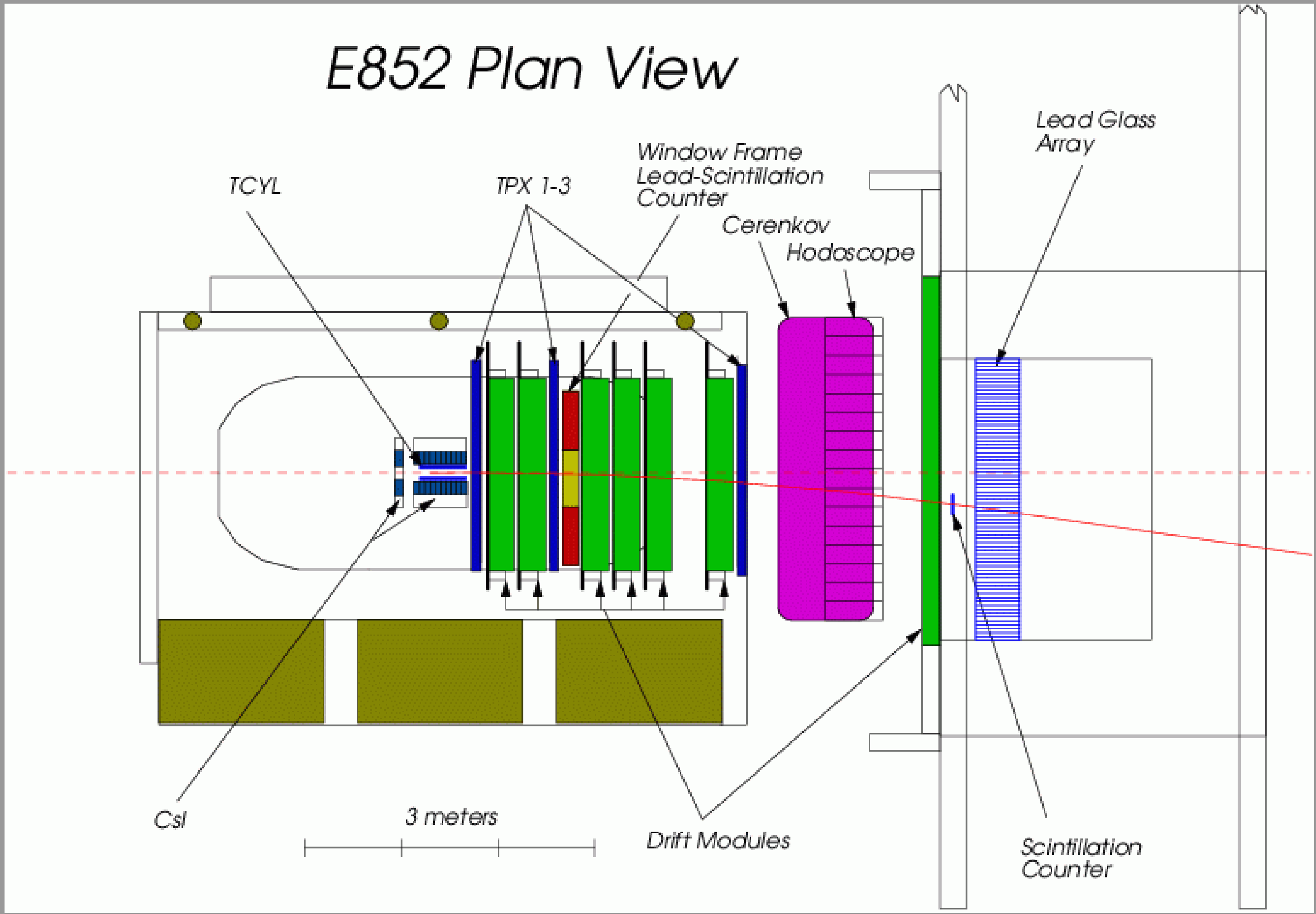
Collaboration	Mass (GeV/c^2)	
UKQCD '97	1.87	Lacock *et al.*, Phys. Lett. **B401**, 308.
MILC '97	1.97	Bernard *et al.*, Phys. Rev. **D56**, 7039.
MILC '99	2.11	Bernard *et al.*, Nucl. Phys. B **73**, 264.
Lacock&Schilling	1.9	Lacock & Schilling, Nucl. Phys. B **73**, 261.

Light Quark $J^{PC}=1^{-+}$ Flux-Tube $^3P_0$ Branching Ratio

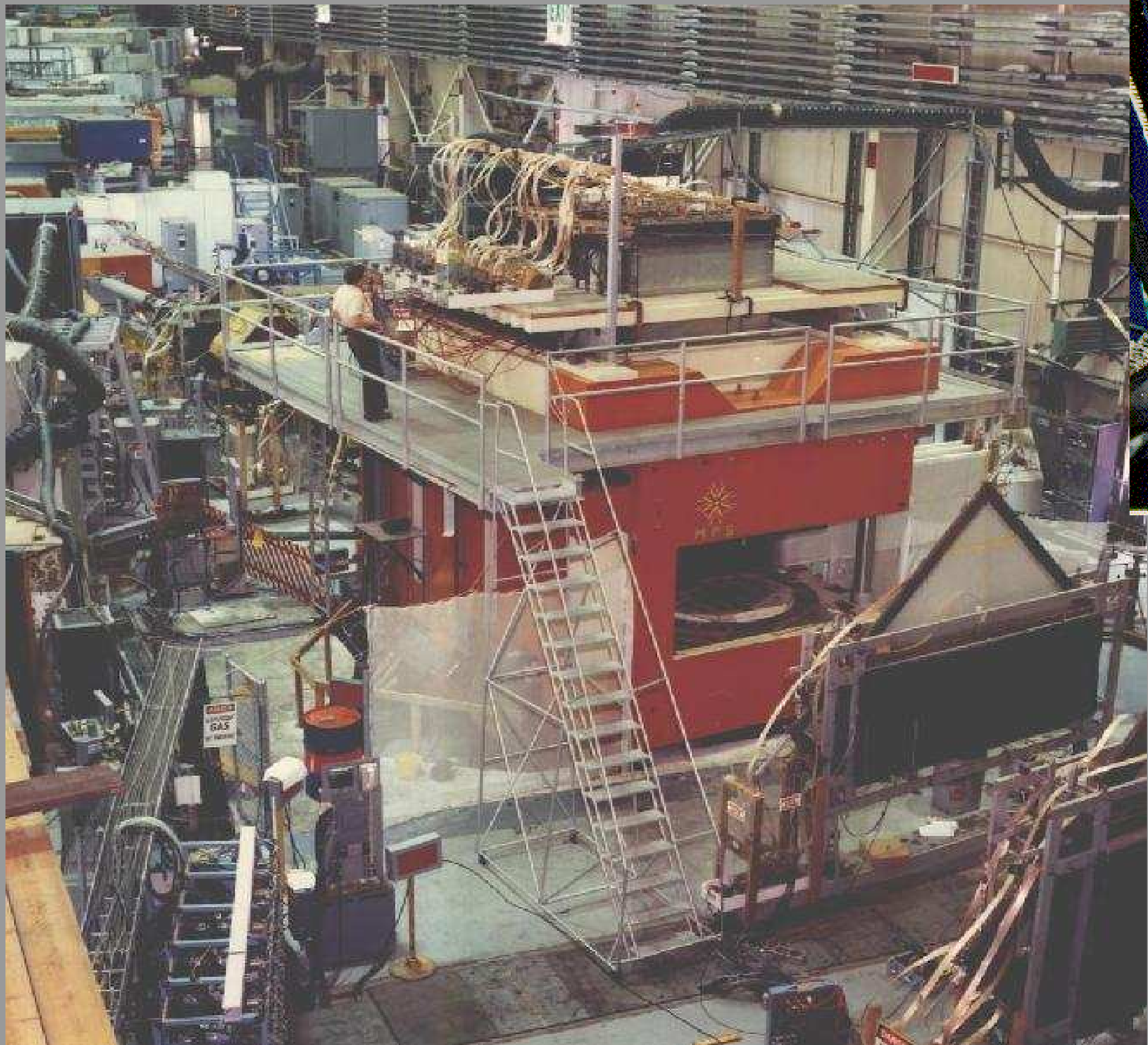
$f_1\pi$	$b_1\pi$	$\rho\pi$	$\eta\pi$	$\eta'\pi$
60	170	5-20	0-10	0-10

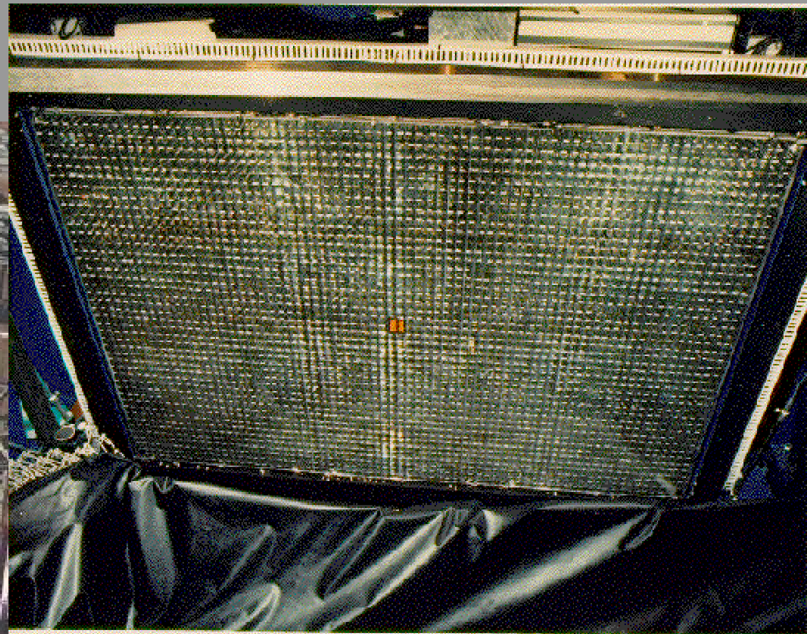
Close & Page, Nucl. Phys. B **443**, 233 (1995)

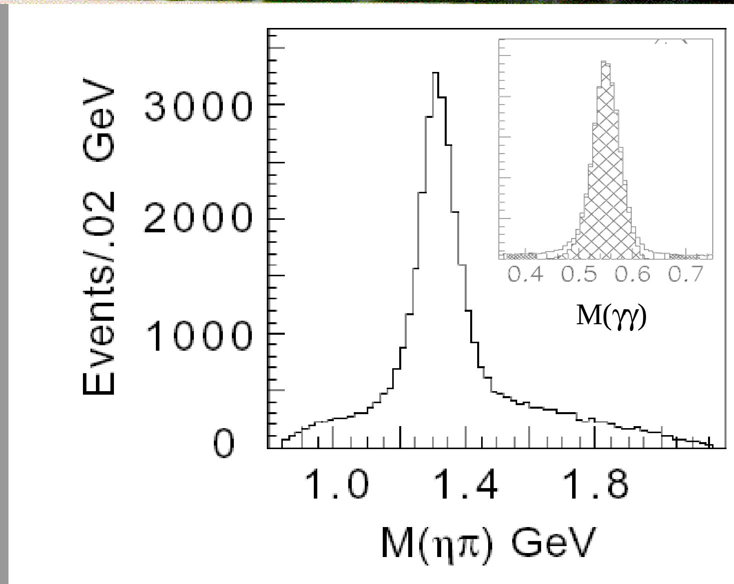
E852: MPS/Pb Glass/Cerenkov Counter



E852 (1994-1998) Brookhaven Multi-Particle Spectrometer



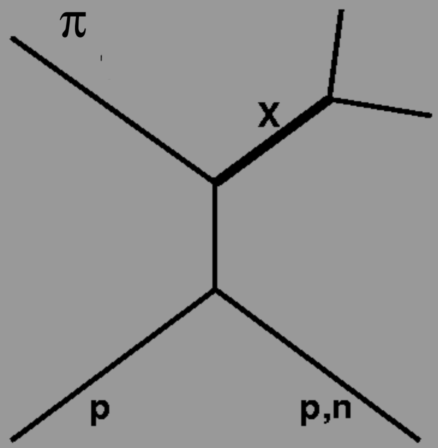


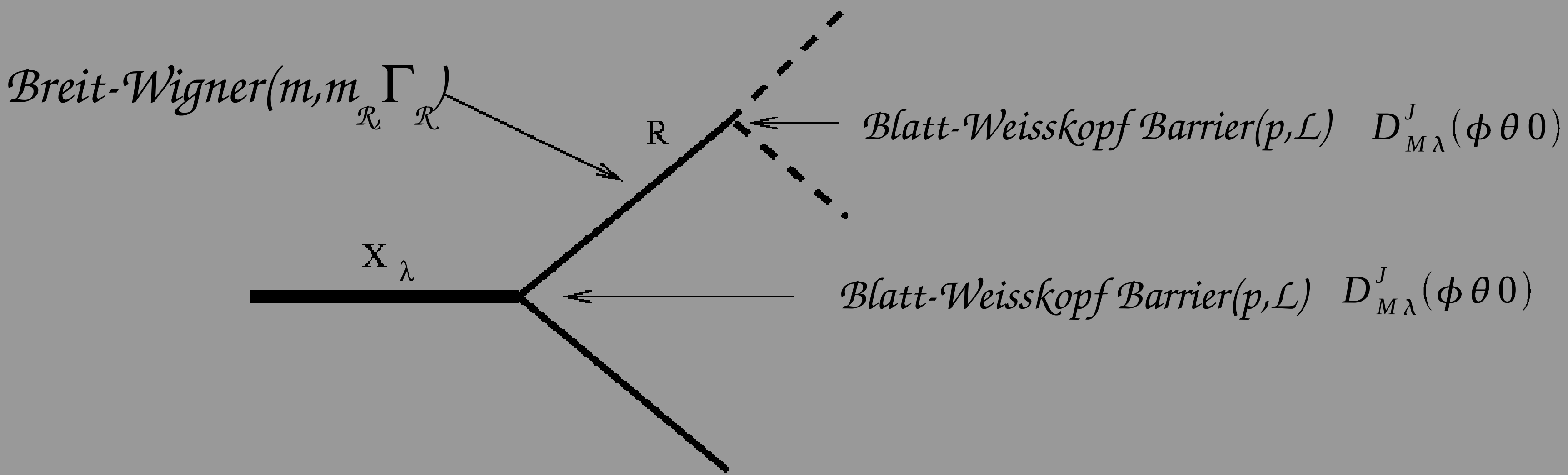


Partial Wave Analysis Formalism

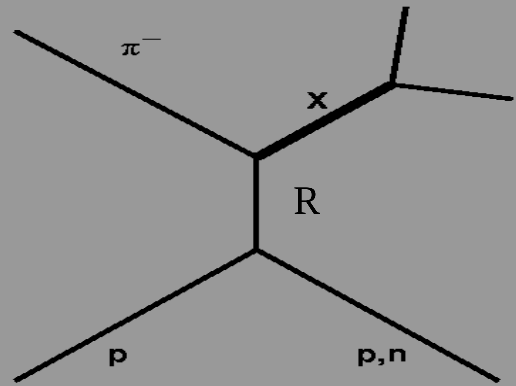
Angular Distributions:

$$I(\tau) = \sum_{\epsilon k} \sum_{X} \left| \quad \right|^2$$





Reflectivity



The operator Π_y: reflection through the production plane

Helicity states satisfy: $\Pi_y|\vec{p},a,\lambda\rangle=\eta(-1)^{J-\lambda}|\vec{p},a,-\lambda\rangle$

Eigenstates of Π_y: $|\epsilon a m\rangle=[|a m\rangle+\epsilon\eta(-1)^{J-m}|a -m\rangle]\theta(m)$

where: $\theta(m)=\begin{cases}\frac{1}{\sqrt{2}}, m>0\\ \frac{1}{2}, m=0\\ 0, m<0\end{cases}$

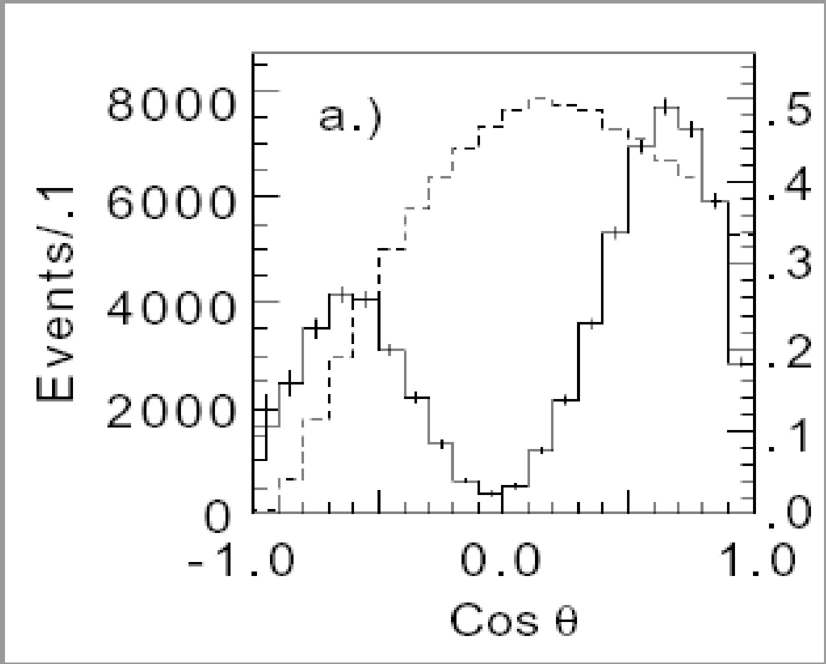
The spin density matrix in this basis:

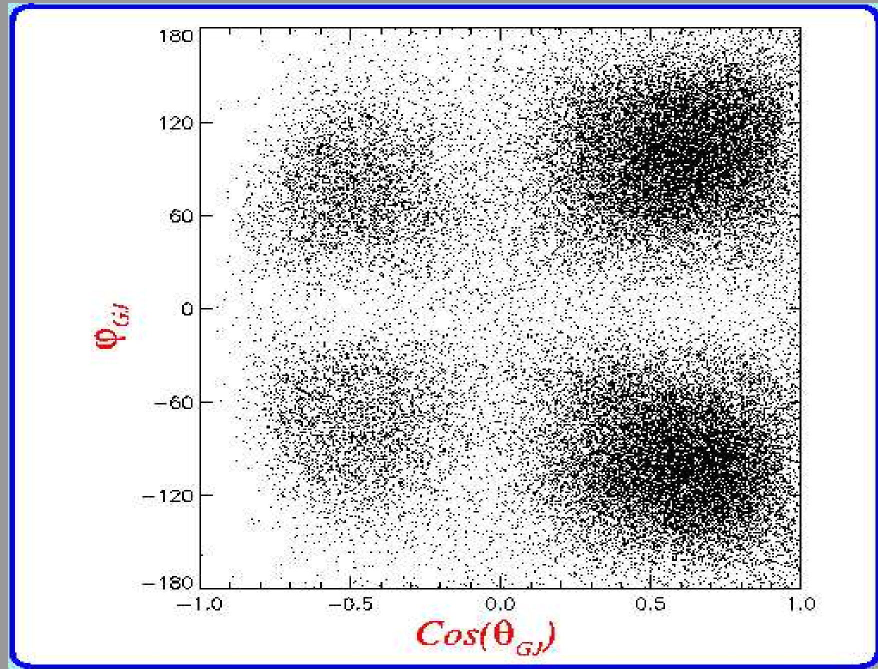
$${}^{\epsilon\epsilon'}\rho^{aa'}_{mm'}=[\rho^{aa'}_{mm'}+\epsilon\epsilon'(-1)^{J-J'}(-1)^{m-m'}\eta\eta'\rho^{aa'}_{-m-m'}+\rho^{aa'}_{-mm'}\epsilon(-1)^{J-m}\eta+\rho^{aa'}_{m-m'}\epsilon'(-1)^{J'-m'}\eta']\theta(m)\theta(m')$$

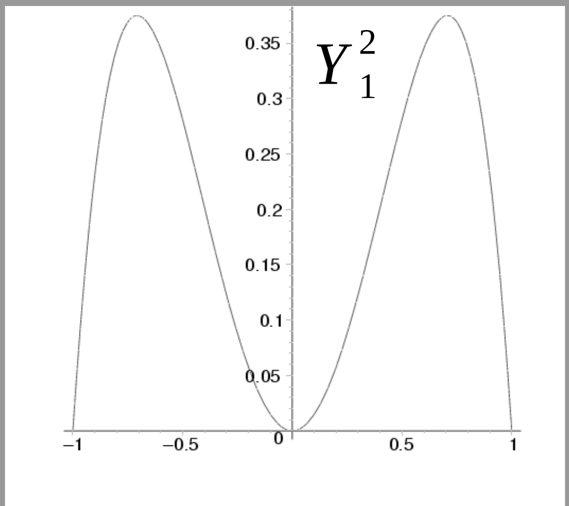
$${}^{\epsilon}\rho=\begin{pmatrix}{}^{(+)}\rho & 0\\ 0 & {}^{(-)}\rho\end{pmatrix} \quad = \quad 0 \quad if \quad \epsilon\neq\epsilon'$$

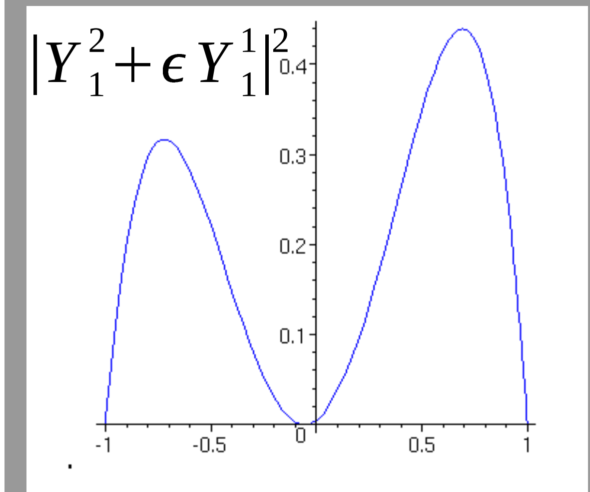
Chung and Trueman, PRD 11, #3, 633 (1975)

E852 (1994) $\pi^- p \rightarrow \eta \pi^- p$ P_1-D_1 Interference









$$\epsilon^+ : |+1> - |-1> \propto \sin^2(\phi)$$
$$\epsilon^- : |+1> + |-1> \propto \cos^2(\phi)$$

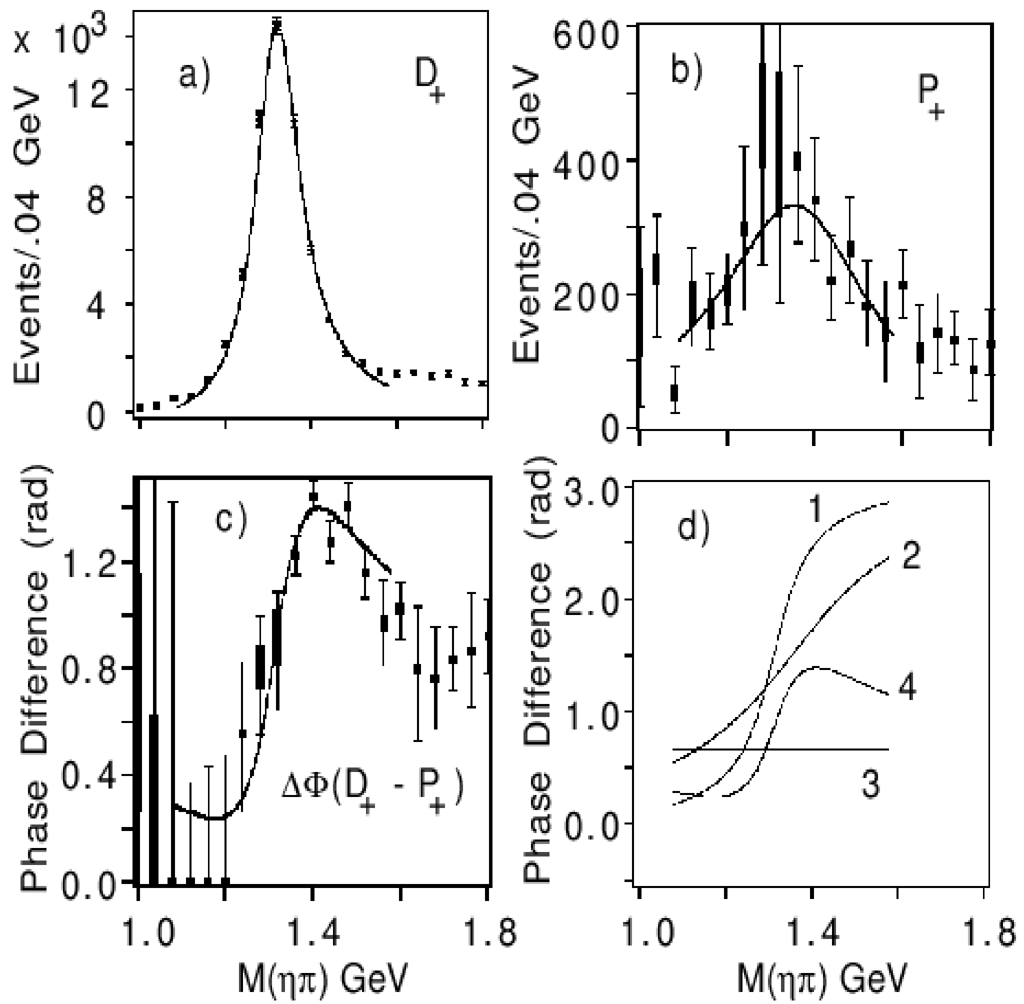
E852 (1994)

$$\pi^- p \rightarrow \eta \pi^- p$$

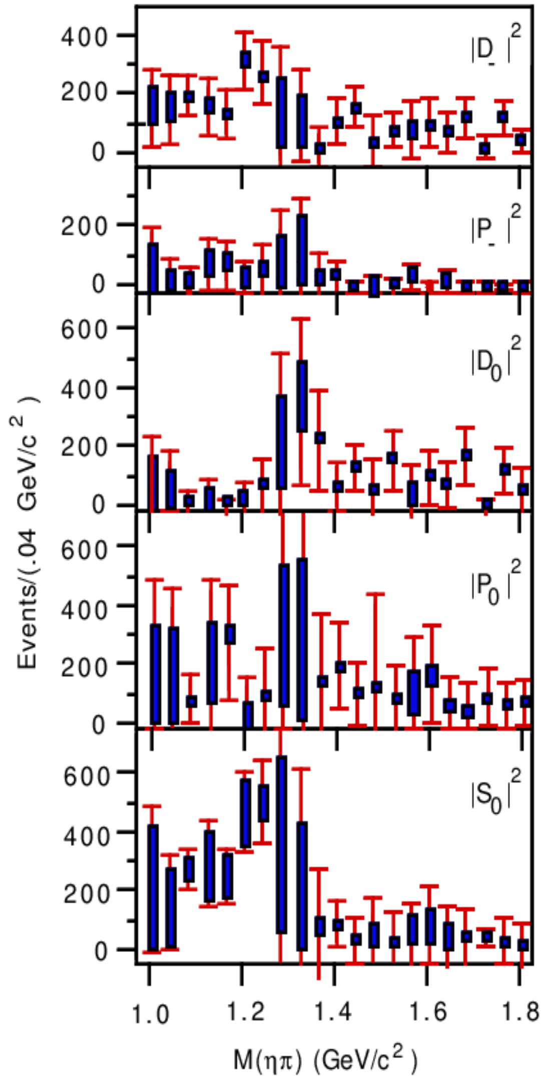
$$M(\pi_1(1400)) = 1370 \pm 16^{+50}_{-30}\ MeV/c^2$$

$$\Gamma(\pi_1(1400)) = 385 \pm 40^{+29}_{-47}\ MeV/c^2$$

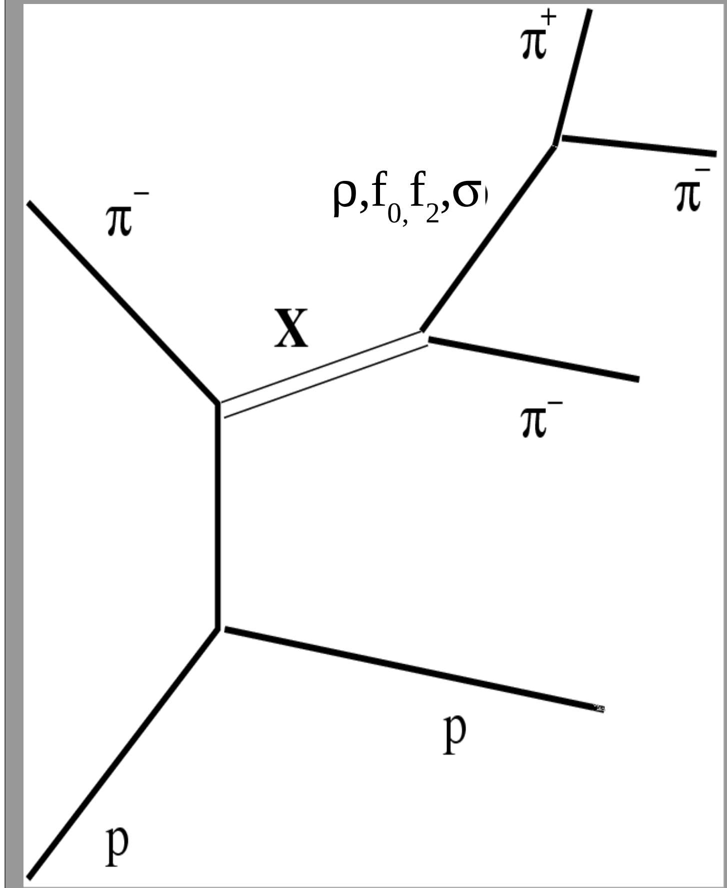
Natural Parity Exchange

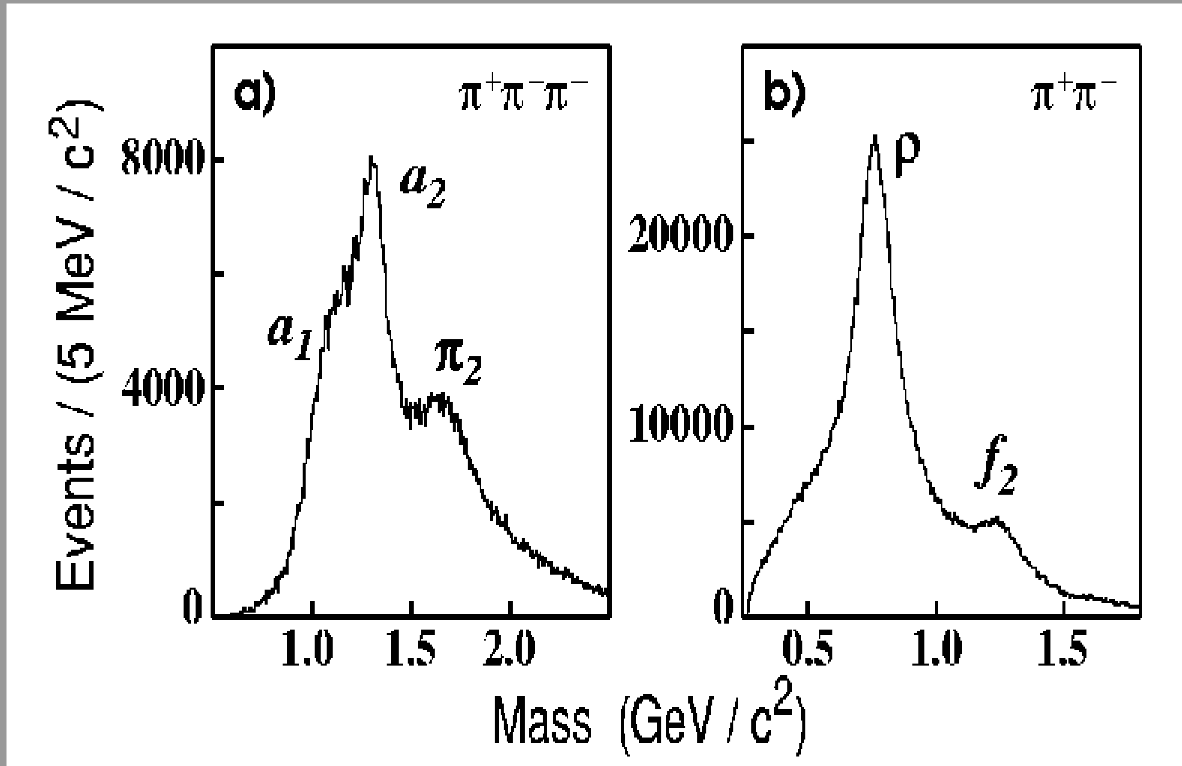


Unnatural Parity Exchange



E852 (1994) $\pi^- p \rightarrow \pi^+ \pi^- \pi^- p$ Phys. Rev. **D65**, 072001 (2002)

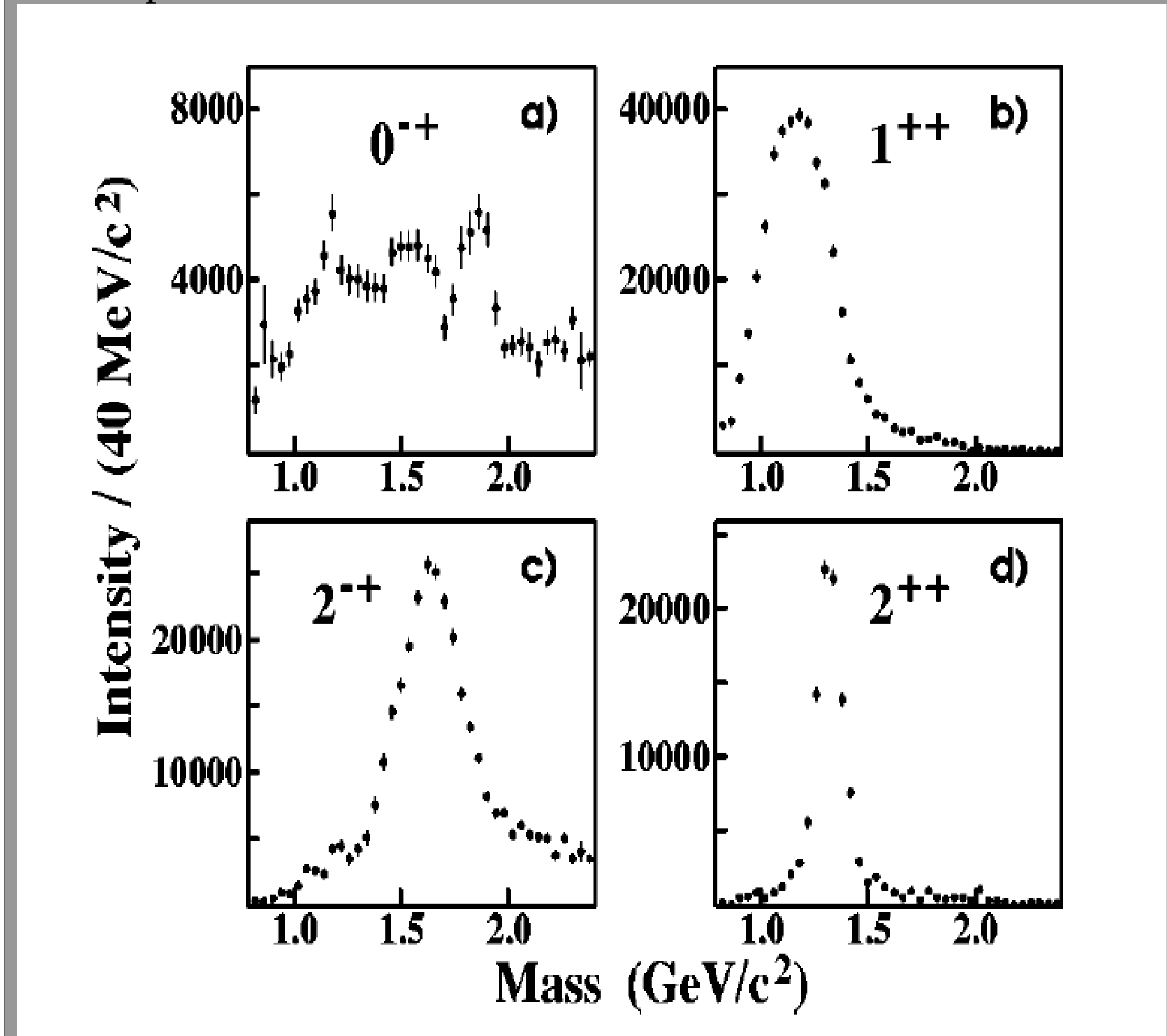




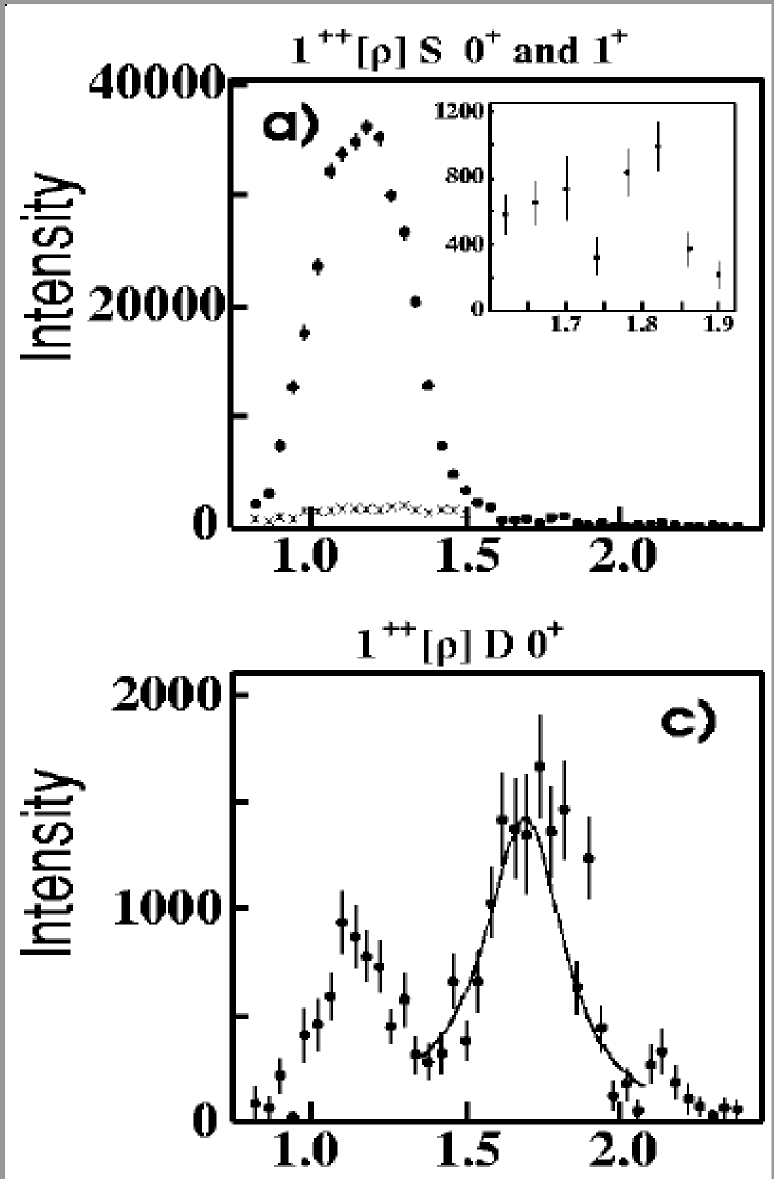
250,000 Events

E852 (1994) $\pi^- p \rightarrow \pi^+ \pi^- \pi^- p$

Principle Waves:



E852 (1994) $\pi^- p \to \pi^+ \pi^- \pi^- p$ $J^{PC} = 1^{++}$ Wave



Barnes,Close,Page, & Swanson PRD55:4157-4188 (1997)

$$a_1(1700)_H \to (\rho\pi)_S : (\rho\pi)_D \approx 20:1$$

$$M = 1714 \pm 9_{stat} \pm 36_{sys}\ MeV/c^2$$

$$\Gamma = 308 \pm 37_{stat} \pm 62_{sys}\ MeV/c^2$$

E852 (1994)

$J^{PC} = 2^{-+}$ (π_2)

$\pi^- p \rightarrow \pi^+ \pi^- \pi^- p$

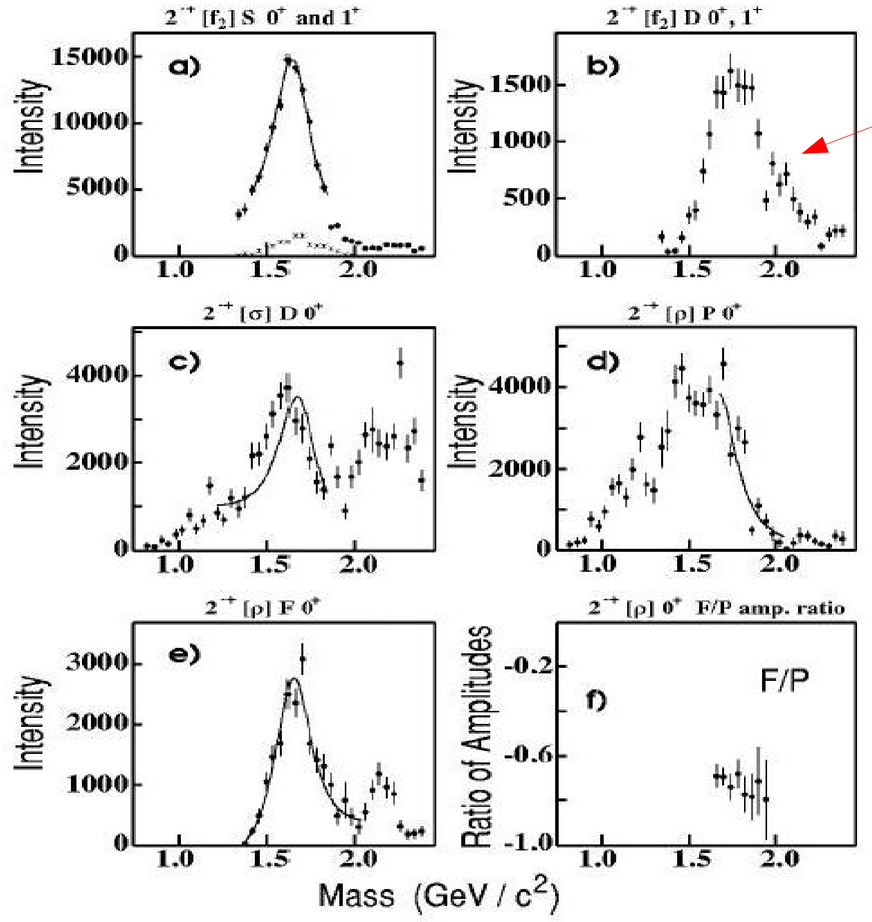


FIG. 10. (a) Intensity of the $2^{-+}[f_2]S0^+$ (points) and $2^{-+}[f_2]S1^+$ (crosses) waves; (b) combined intensity of the $2^{-+}[f_2]D$ $M^\epsilon = 0^+, 1^+$ waves; (c) intensity of the $2^{-+}[\sigma]D0^+$ wave; (d) intensity of the $2^{-+}[\rho]P0^+$ wave; (e) intensity of the $2^{-+}[\rho]F0^+$ wave (27-wave fit); (f) ratio of the $2^{-+}[\rho]F0^+$ wave amplitude to the $2^{-+}[\rho]P0^+$ wave amplitude (27-wave fit). Curves show the mass-dependent fits of the $\pi_2(1670)$ with parameters from Eq. (8).

$\pi_2(1900)$

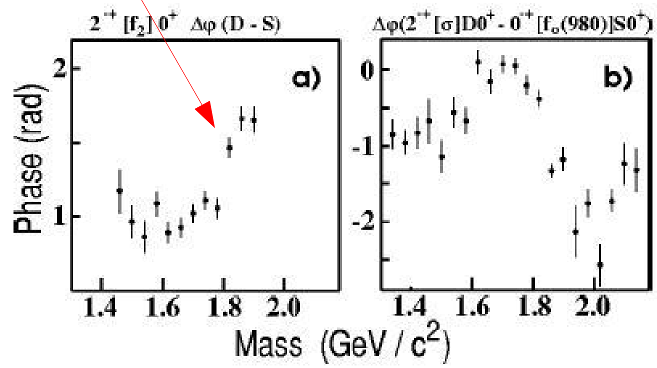


FIG. 11. Phase difference between (a) the $2^{-+}[f_2]D0^+$ and $2^{-+}[f_2]S0^+$ waves; (b) the $2^{-+}[\sigma]D0^+$ and $0^{-+}[f_0(980)]S0^+$ waves.

$$M = 1676 \pm 3_{stat} \pm 8_{sys}\ MeV/c^2$$

$$\Gamma = 254 \pm 3_{stat} \pm 31_{sys}\ MeV/c^2$$

$$M_{PDG} = 1670 \pm 20\ MeV/c^2$$

$$\Gamma_{PDG} = 259 \pm 11\ MeV/c^2$$

E852 (1994)

$J^{PC} = 0^{-+}$ (π)

$\pi^- p \to \pi^+ \pi^- \pi^- p$

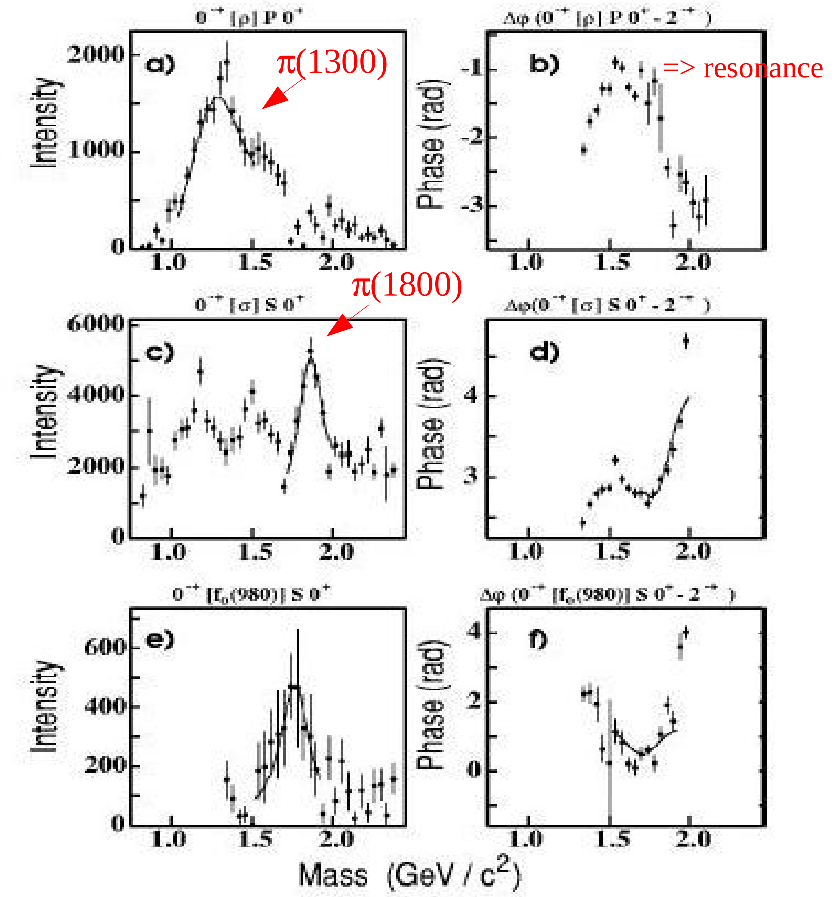


FIG. 12. Intensities of the (a) $0^{-+}[\rho]P0^+$, (c) $0^{-+}[\sigma]S0^+$, (e) $0^{-+}[f_0(980)]S0^+$ waves and their corresponding phase differences (b,d,f) with respect to the $2^{-+}[f_2]S0^+$ wave. Curves show the mass-dependent fits of (a) the $\pi(1300)$ with parameters from Eq. (12); (c,d) the $\pi(1800)$ with parameters from Eq. (14); (e,f) the $\pi(1800)$ with parameters from Eq. (13).

π(1300)

$$M = 1343 \pm 15_{stat} \pm 24_{sys}\ MeV/c^2$$

$$\Gamma = 449 \pm 39_{stat} \pm 47_{sys}\ MeV/c^2$$

$$M_{PDG} = 1300 \pm 100\ MeV/c^2$$

$$\Gamma_{PDG} = 200 - 600\ MeV/c^2$$

$\pi(1800) \to f_0(980)\pi$

$$M = 1774 \pm 18_{stat} \pm 20_{sys}\ MeV/c^2$$

$$\Gamma = 223 \pm 48_{stat} \pm 50_{sys}\ MeV/c^2$$

$\pi(1800) \to \sigma\pi$

$$M = 1863 \pm 9_{stat} \pm 10_{sys}\ MeV/c^2$$

$$\Gamma = 191 \pm 21_{stat} \pm 20_{sys}\ MeV/c^2$$

E852 (1994) $J^{PC} = 3^{++}(a_3)$ $\pi^- p \rightarrow \pi^+ \pi^- \pi^- p$

$a_3(1875) \rightarrow \rho\pi(D)$

$a_3(1875) \rightarrow f_2(1270)\pi(P)$

$a_3(1875) \rightarrow \rho_3(1690)\pi(S)$

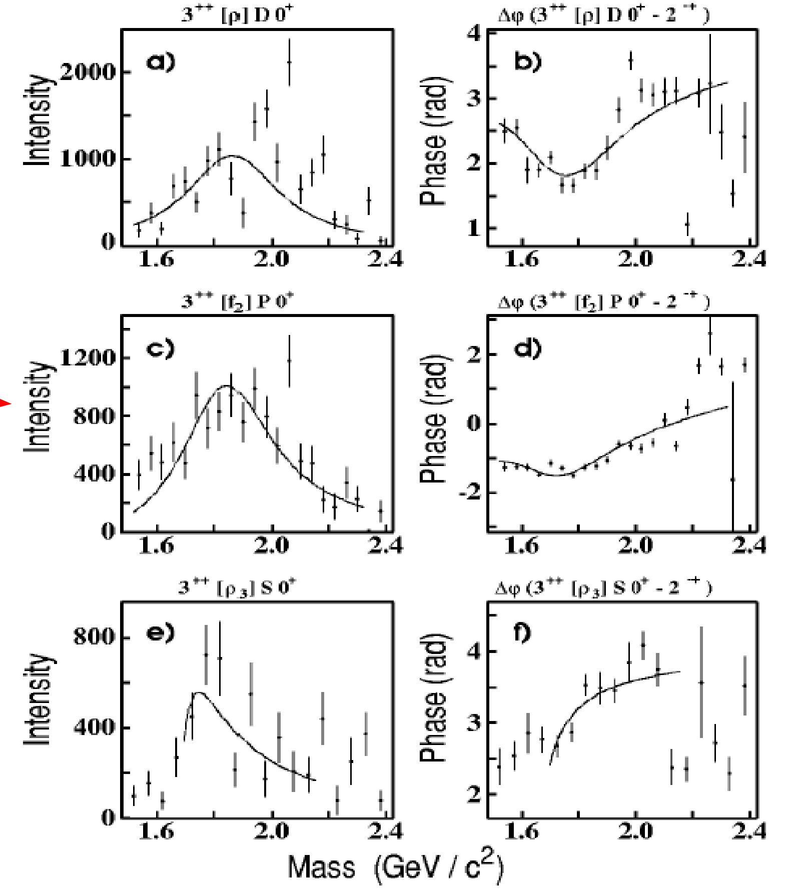


FIG. 16. Intensities of the (a) $3^{++}[\rho]D0^+$, (c) $3^{++}[f_2]P0^+$, (e) $3^{++}[\rho_3]S0^+$ waves and their corresponding phase differences (b,d,f) with respect to the $2^{-+}[f_2]S0^+$ wave. The 27-wave rank-1 fit is shown. Curves show the mass-dependent fits of the $a_3(1874)$ with parameters from Eq. (19). Note that the fitted $a_3(1874)$ mass and width vary considerably in the fits done separately for each decay mode leading to large parameter errors in Eq. (19).

$a_3(1875)$

$$M = 1874 \pm 43_{stat} \pm 96_{sys}\ MeV/c^2$$

$$\Gamma = 385 \pm 121_{stat} \pm 114_{sys}\ MeV/c^2$$

E852 (1994)

$J^{PC} = 4^{++} (a_4)$

$\pi^- p \rightarrow \pi^+ \pi^- \pi^- p$

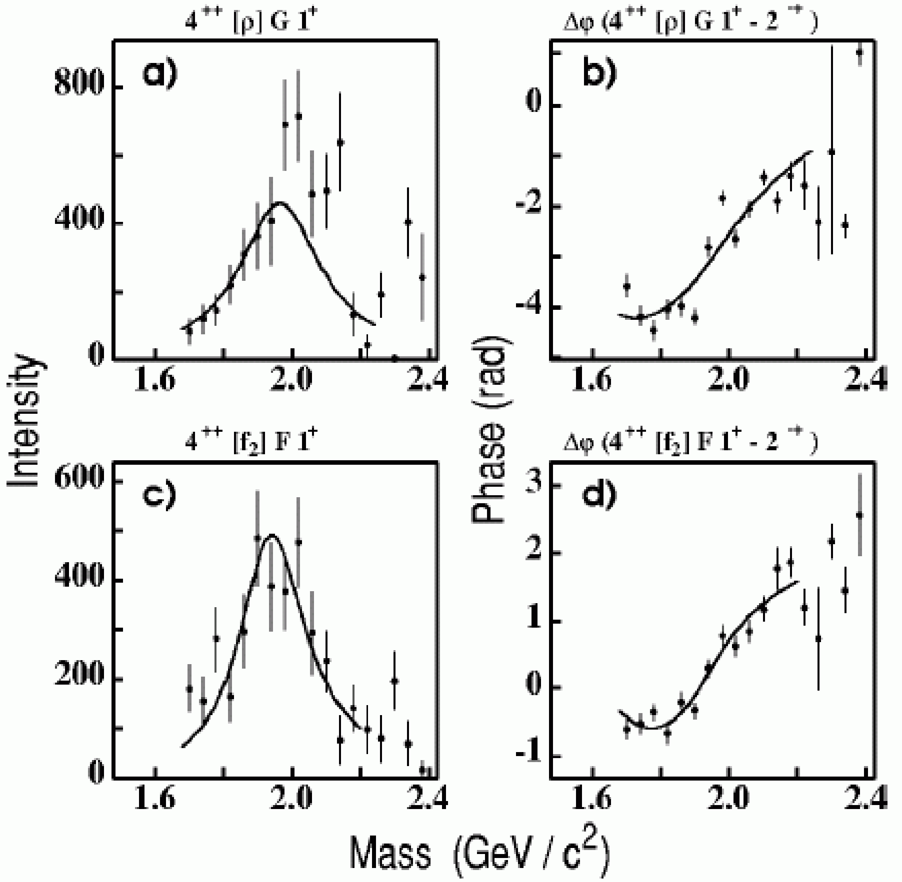


FIG. 17. Intensities of the (a) $4^{++}[\rho]G1^+$, (c) $4^{++}[f_2]F1^+$ waves and their corresponding phase differences (b,d) with respect to the $2^{-+}[f_2]S0^+$ wave. The 27-wave fit is shown. Curves show the mass-dependent fits of the $a_4(2040)$ with parameters from Eq. (21).

$$a_4(2040) \rightarrow \rho\pi\,,\ f_2(1270)\pi$$

$$M = 1996 \pm 25_{stat} \pm 43_{sys}\ MeV/c^2$$

$$\Gamma = 298 \pm 81_{stat} \pm 85_{sys}\ MeV/c^2$$

$$\frac{BR[a_4(2040) \rightarrow \rho\pi]}{BR[a_4(2040) \rightarrow f_2(1270)\pi]} = 1.1 \pm 0.2_{stat} \pm 0.2_{sys}$$

$$M_{PDG} = 2011 \pm 13\ MeV/c^2$$

$$\Gamma_{PDG} = 360 \pm 40\ MeV/c^2$$

$\pi^-(18\,GeV/c)\,p \rightarrow \pi^+\pi^-\pi^-\,p$ $J^{PC} = 1^{-+}$ Exotic $\pi_1(1600)$

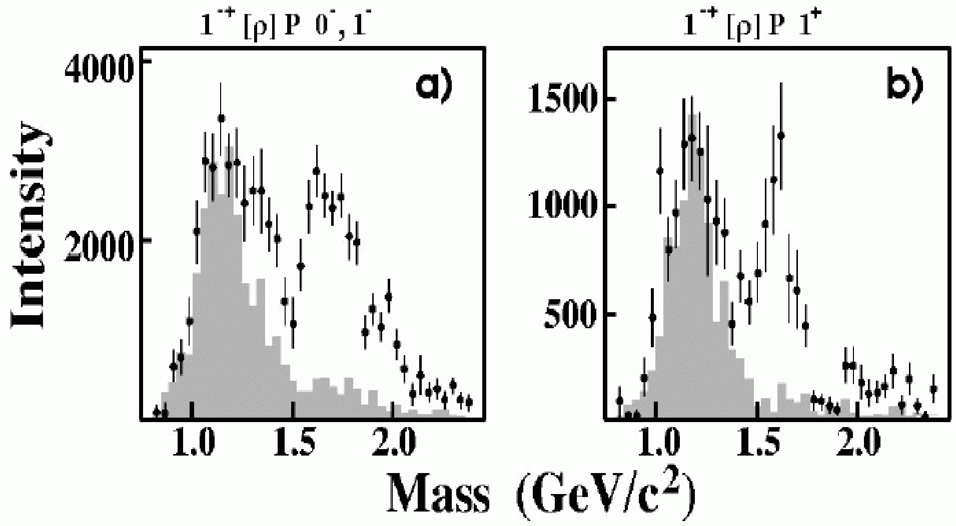
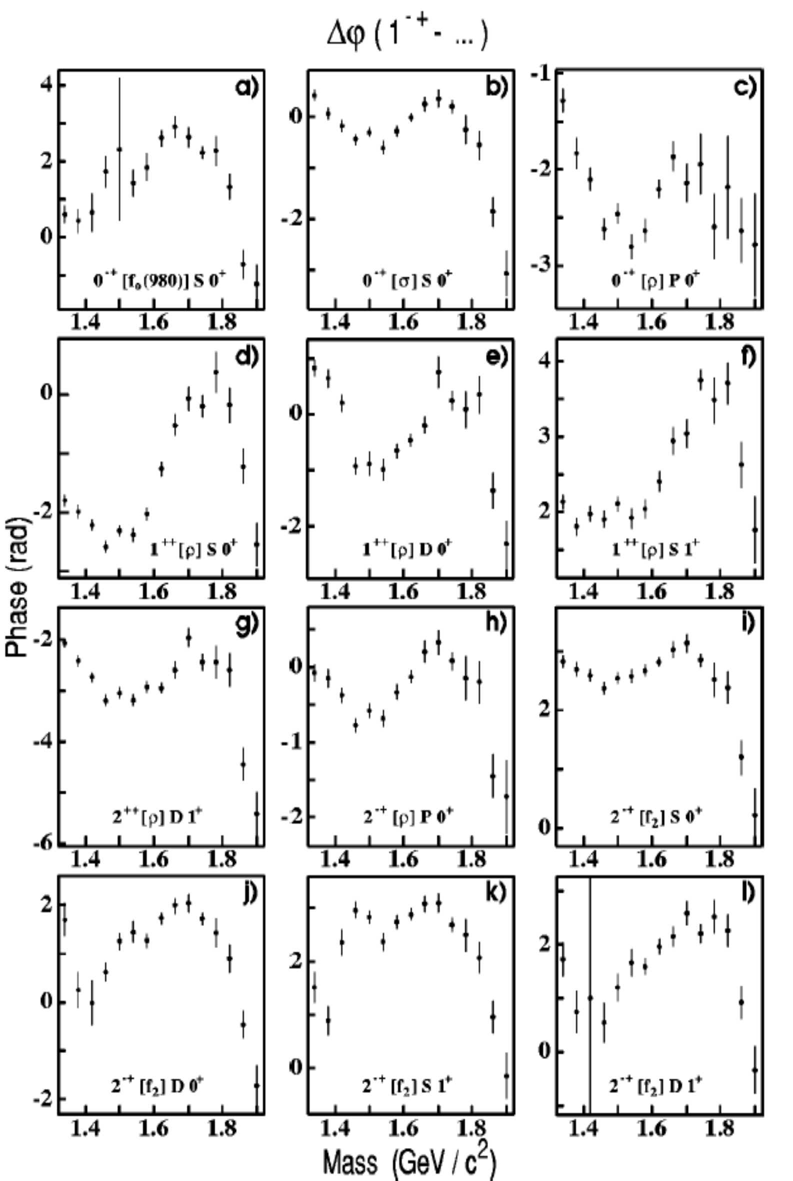


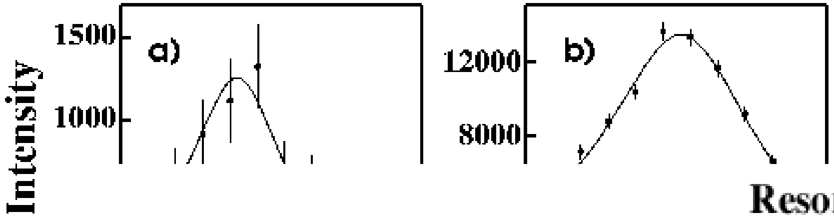
FIG. 18. Wave intensities of the $1^{-+}[\rho]P$ exotic waves: (a) the $M^{\epsilon}=0^-$ and 1^- waves combined; (b) the $M^{\epsilon}=1^+$ wave. The 21-wave rank-1 PWA fit to the data is shown as the points with error bars and the shaded histograms show estimated contributions from all non-exotic waves due to leakage.



E852 (1994) $\pi^- p \rightarrow \pi^+ \pi^- \pi^- p$ $J^{PC} = 1^{-+}$ Exotic $\pi_1(1600)/\pi_2(1670)$

$$M(\pi_1(1600)) = 1598 \pm 8^{+29}_{-47}\ MeV/c^2$$

$$\Gamma(\pi_1(1600)) = 168 \pm 20^{+150}_{-12}\ MeV/c^2$$



Resonance parameters

J^{PC} Resonance and decay mode(s) used	M, MeV/c^2	Γ, MeV/c^2
$0^{-+}\ \pi(1300) \rightarrow \rho(770)\pi$	$1343 \pm 15 \pm 24$	$449 \pm 39 \pm 47$
$0^{-+}\ \pi(1800) \rightarrow f_0(980)\pi$	$1774 \pm 18 \pm 20$	$223 \pm 48 \pm 50$
$0^{-+}\ \pi(1800) \rightarrow \sigma\pi$	$1863 \pm 9 \pm 10$	$191 \pm 21 \pm 20$
$1^{-+}\ \pi_1(1600) \rightarrow \rho(770)\pi$	$1593 \pm 8^{+29}_{-47}$	$168 \pm 20^{+150}_{-12}$
$1^{++}\ a_1(1700) \rightarrow \rho(770)\pi$	$1714 \pm 9 \pm 36$	$308 \pm 37 \pm 62$
$2^{-+}\ \pi_2(1670) \rightarrow f_2(1270)\pi$	$1676 \pm 3 \pm 8$	$254 \pm 3 \pm 31$
$2^{++}\ a_2(1320) \rightarrow \rho(770)\pi$	$1326 \pm 2 \pm 2$	$108 \pm 3 \pm 15$
$3^{++}\ a_3(1874) \rightarrow \rho(770)\pi, f_2(1270)\pi, \rho_3(1690)\pi$	$1874 \pm 43 \pm 96$	$385 \pm 121 \pm 114$
$4^{++}\ a_4(2040) \rightarrow \rho(770)\pi, f_2(1270)\pi$	$1996 \pm 25 \pm 43$	$298 \pm 81 \pm 85$

Phase (rad)

FI

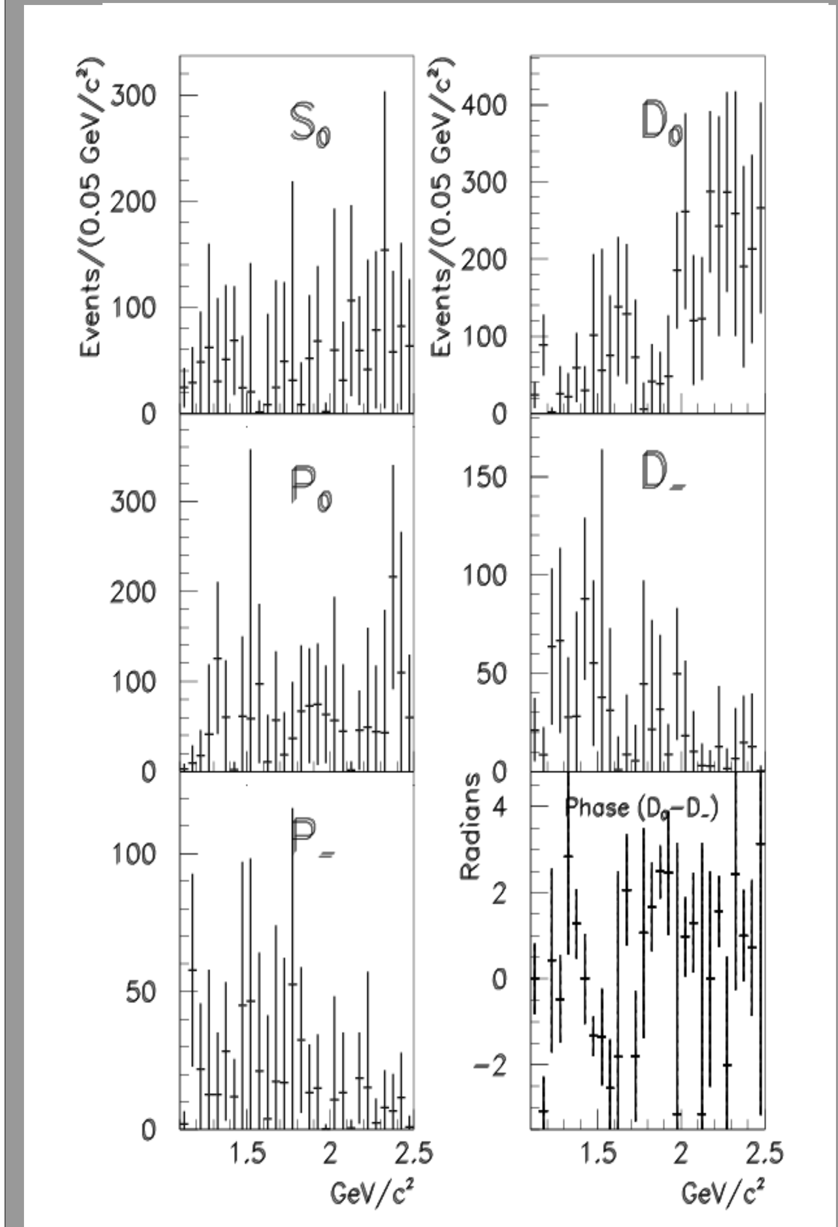
1^{-+}[

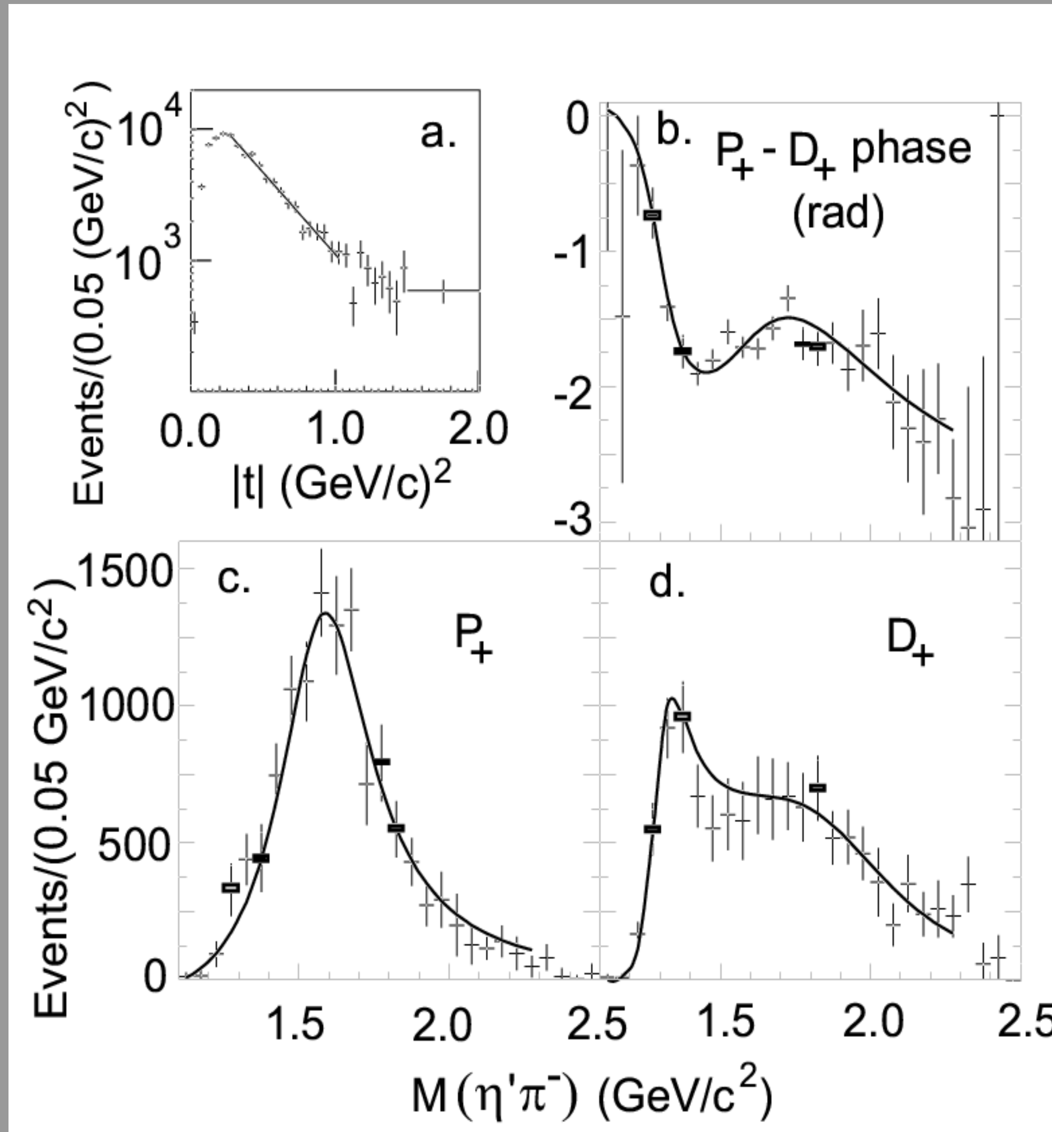
$1^{-+}[\rho(770)]P1^+$ wave intensity. (b) $2^{-+}[f_2(1270)]S0^+$ wave intensity. (c) Phase difference between the $1^{-+}[\rho(770)]P1^+$ and $2^{-+}[f_2(1270)]S0^+$ waves. (d) Phase motion of the $1^{-+}[\rho(770)]P1^+$ wave (1), $2^{-+}[f_2(1270)]S0^+$ wave (2), and the production phase between them (3).

E852 (1995) $\pi^- p \to \eta' \pi^- p, \; \eta' \to \eta \pi^+ \pi^-, \; \eta \to \gamma\gamma$ 6048 Events

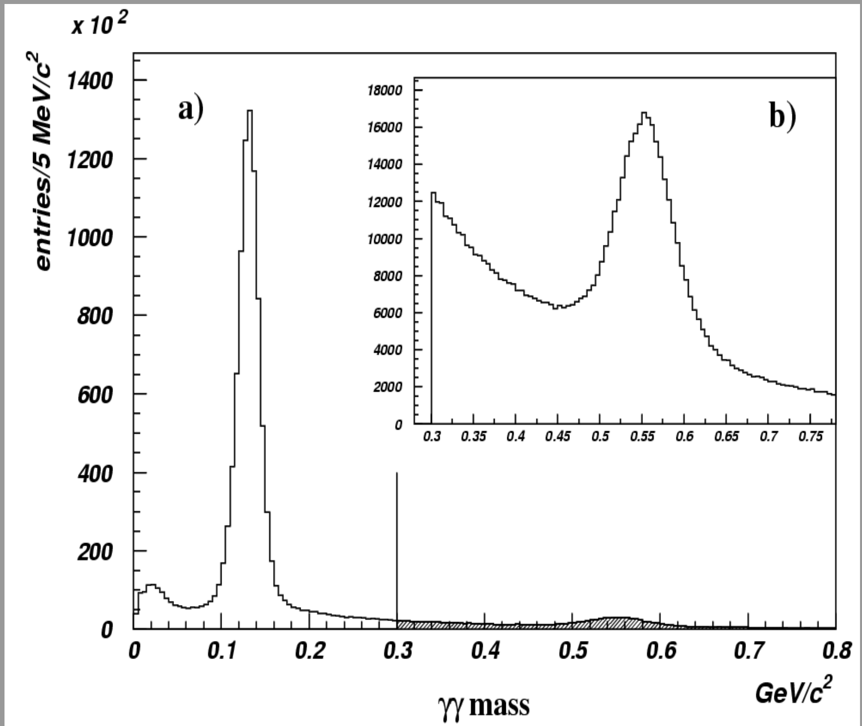
$M(\pi_1(1600)) = 1597 \pm 10^{+45}_{-10} \; MeV/c^2$

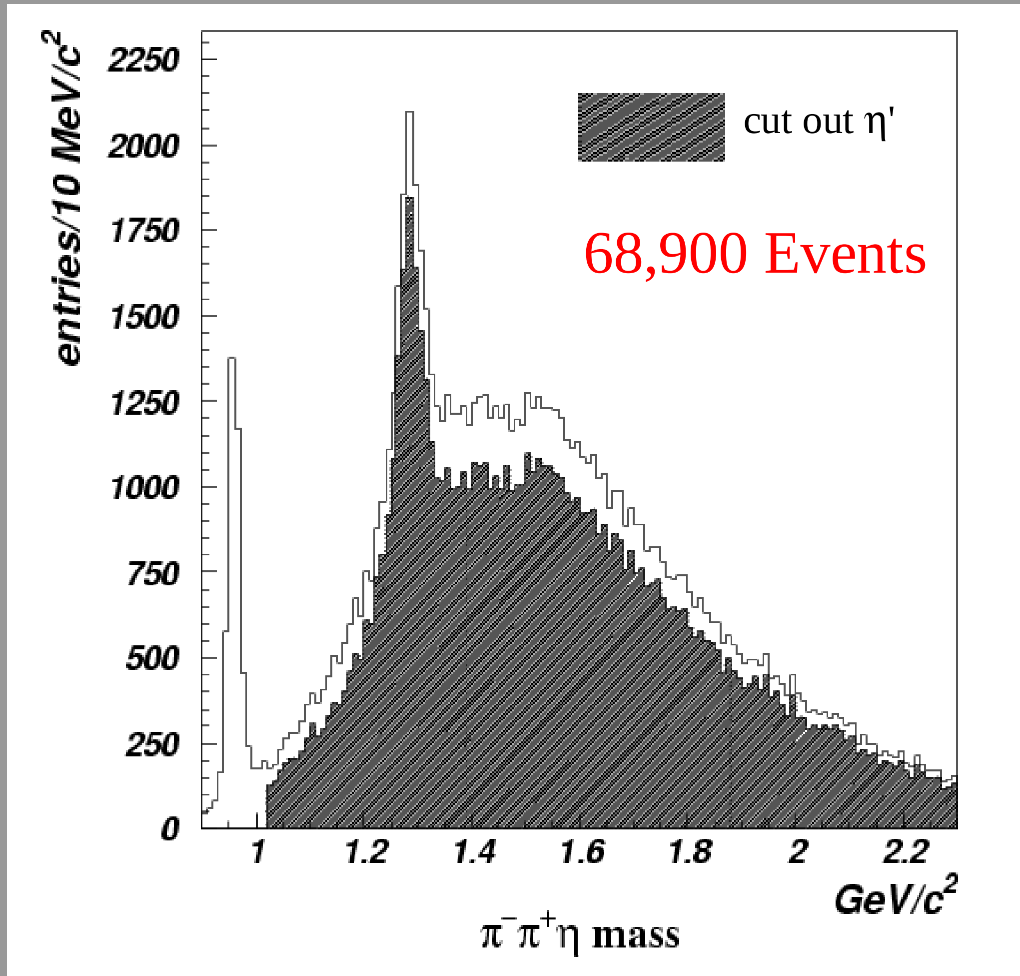
$\Gamma(\pi_1(1600)) = 340 \pm 40 \pm 50 \; MeV/c^2$





E852 $\pi^- p \rightarrow \eta \pi^+ \pi^- \pi^- p$





BNL E818 (1990) $\pi^- p \to K^+ K^0 \pi^- \pi^- p$ $f_1(1285) \to K^+ K^0 \pi^-$

747 events

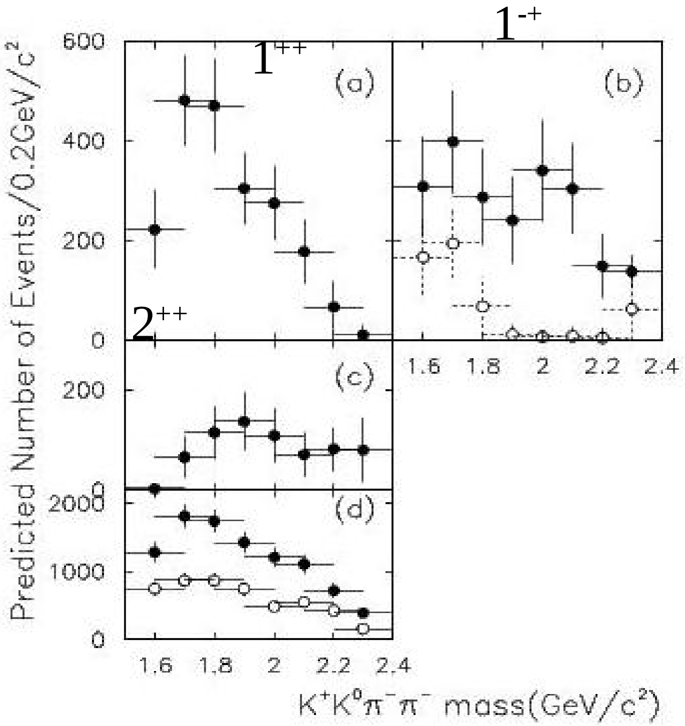


Fig. 3. The partial-wave intensity distributions as a function of $f_1\pi^-$ mass. (a) $J^{PC}M^\epsilon = 1^{++}0^+$ wave. (b) $J^{PC}M^\epsilon = 1^{-+}1^+$ wave with combined $f_1(1285)\pi$ and $\eta(1295)\pi$ decay modes. The dotted spectrum shows $\eta(1295)$ wave only. (c) $J^{PC}M^\epsilon = 2^{++}1^+$. (d) All partial waves included in the fit. The open circles in the plot show the background.

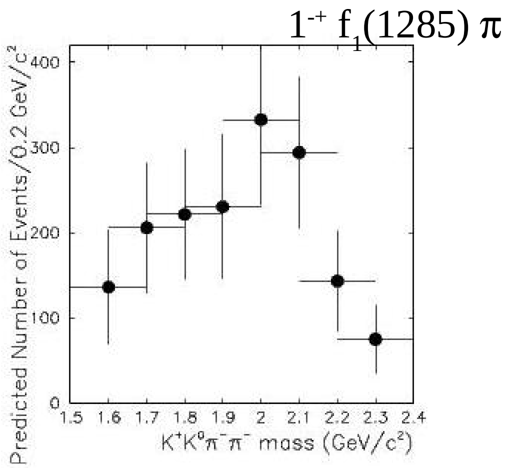


Fig. 4. Predicted number of $1^{-+}[f_1(1285)]1^+$ events as a function of $K^+\bar{K}^0\pi^-\pi^-$ mass.

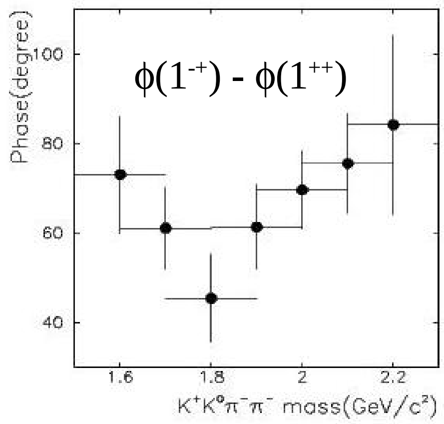


Fig. 5. The relative phase of the $1^{-+}[f_1(1285)]1^+$ wave against the $1^{++}[f_1(1285)]0^+$ wave.

E852 $\pi^- p \rightarrow \eta \pi^+ \pi^- \pi^- p$

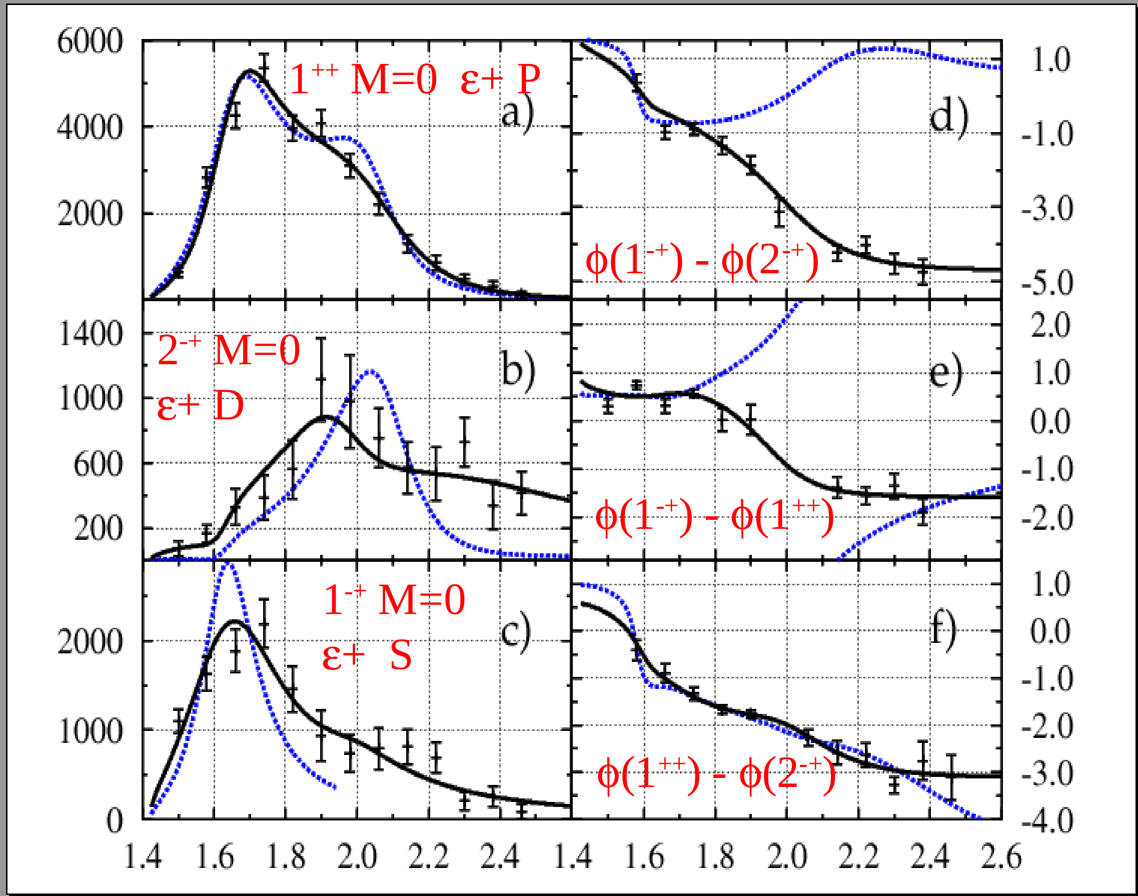
Partial Wave Analysis 53+1 waves

PWA Fit Waveset

$J^{PC}m^{\epsilon}$	primary decay	L	S	# of waves
$0^{-+}0^-$	$\eta(1295)\pi^-$	0	0	2
$0^{-+}0^-$	$a_0^-(980)\sigma$	1	0	1
$2^{++}0^-$	$a_2^-(1320)\sigma$	0	2	1
$2^{++}0^-$	$a_2^-(1320)\rho$	1,3	1,2,3	6
$1^{-+}1^+$	$a_0^-(980)\rho$	0	1	1
$1^{-+}1^+$	$a_1^-(1260)\eta$	0	1	2
$1^{-+}1^+$	$f_1(1285)\pi^-$	0	1	2
$1^{-+}1^+$	$\rho'(1460)\pi^-$	1	1	1
$1^{++}0^+$	$a_0^-(980)\rho$	1	1	1
$1^{++}0^+$	$a_1^-(1260)\eta$	1	1	2
$1^{++}0^+$	$f_1(1285)\pi^-$	1	1	2
$1^{++}0^+$	$a_2^-(1320)\eta$	1	2	1
$1^{++}0^+$	$\rho'(1460)\pi^-$	0,2	1	2
$1^{++}0^+$	$\rho_3(1690)\pi^-$	2	3	1
$2^{-+}0^+$	$a_2^-(1320)\eta$	0	2	1
$2^{-+}0^+$	$\rho'(1460)\pi^-$	1	1	1
$2^{-+}0^+$	$a_1^-(1260)\eta$	2	1	2
$2^{-+}0^+$	$f_1(1285)\pi^-$	2	1	2
$2^{++}1^+$	$\pi_2^-(1670)\eta$	0	2	2
$2^{++}1^+$	$a_2^-(1320)\rho$	1	1,2,3	3
$2^{++}1^+$	$a_2^-(1320)\eta$	1	2	1
$3^{++}0^+$	$a_2^-(1320)\eta$	1	2	1
$3^{++}0,1^+$	$a_2^-(1320)\rho$	1	2,3	4
$3^{++}0^+$	$a_1^-(1260)\eta$	3	1	2
$4^{++}1^+$	$a_2^-(1320)\rho$	1	3	1
$4^{++}1^+$	$a_2^-(1320)\rho$	3	1,2,3	3
$4^{++}1^+$	$a_1^-(1260)\eta$	3	1	2
$4^{++}1^+$	$a_2^-(1320)\eta$	1	2	1
$4^{++}1^+$	$\pi^-(1800)\eta$	4	0	2
Background				1

$f_1(1285)\,\pi^-$ Partial Waves

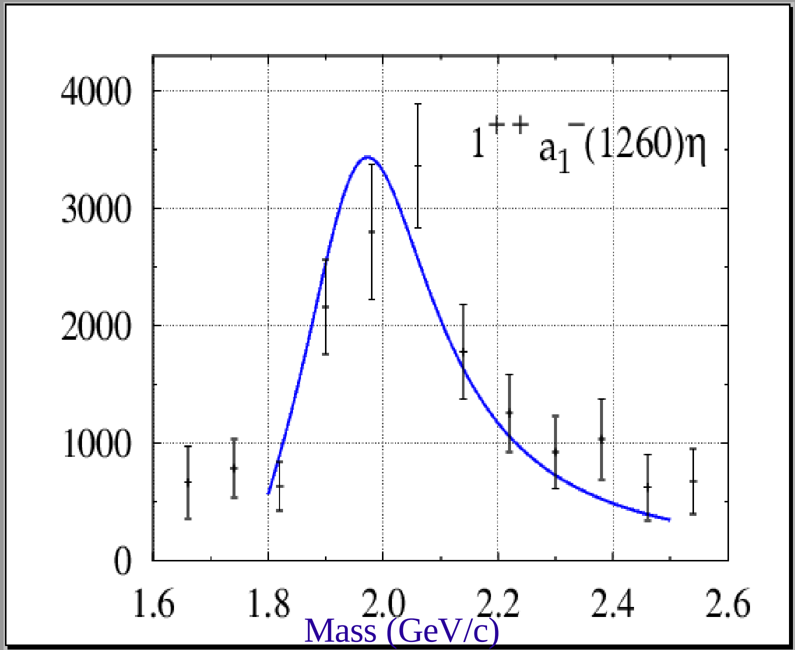
2 $J^{PC}=1^{-+}$ poles
1 $J^{PC}=1^{-+}$ pole



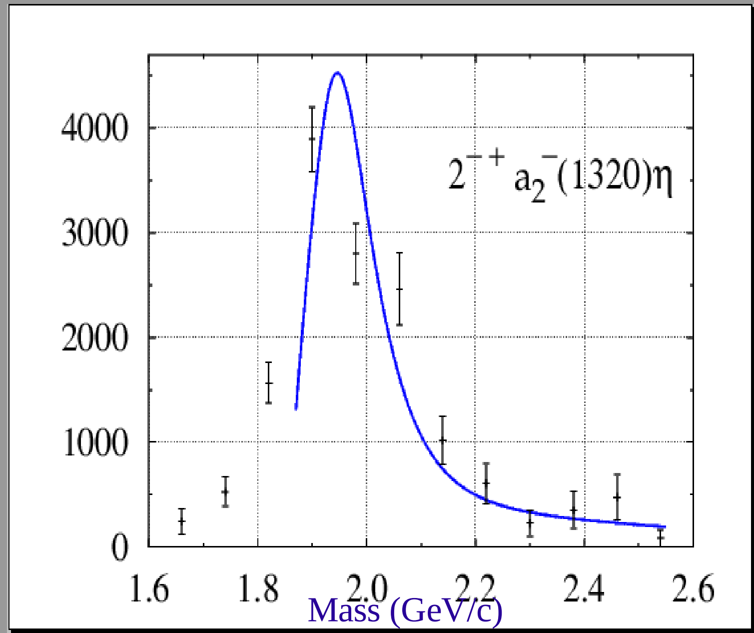
$$\frac{\chi^2}{DOF} = \frac{70.6}{47} = 1.5 \qquad \frac{\chi^2}{DOF} = \frac{383.6}{46} = 8.4$$

Branching Ratios: $a_1(2075)$ and $\pi_2(1991)$ and hybrids[1]

1^{++} M=0 ε^+ a1(1260) η P



2^{-+} M=0 ε^+ $a_2(1320)$ η S



$$\frac{BR[a_1(2075) \rightarrow f_1(1285)\pi]}{BR[a_1(2075) \rightarrow a_1(1260)\eta]} = 2.9$$

hybrid: 3

$$\frac{BR[\pi_2(1991) \rightarrow a_2(1320)\eta]}{BR[\pi_2(1991) \rightarrow f_1(1285)\pi]} = 26.81$$

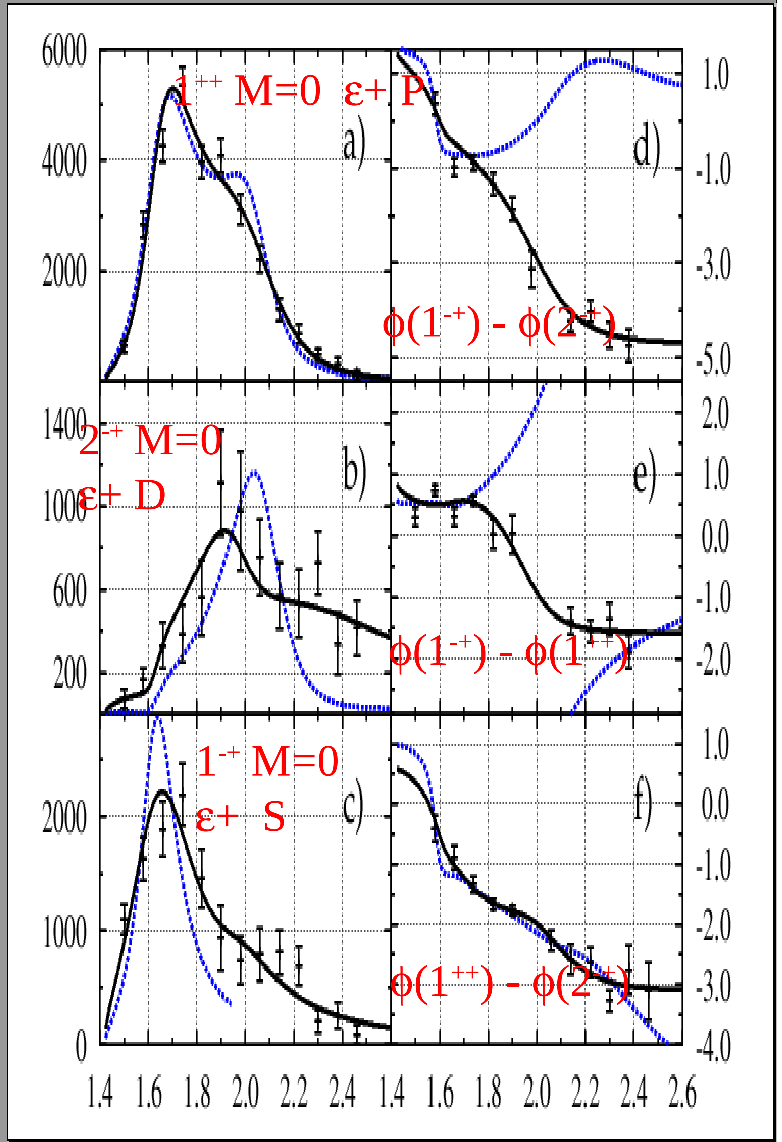
hybrid: 23

[1] Page, Swanson, and Szczepaniak, Phys. Rev. D59, 034016 (1999)

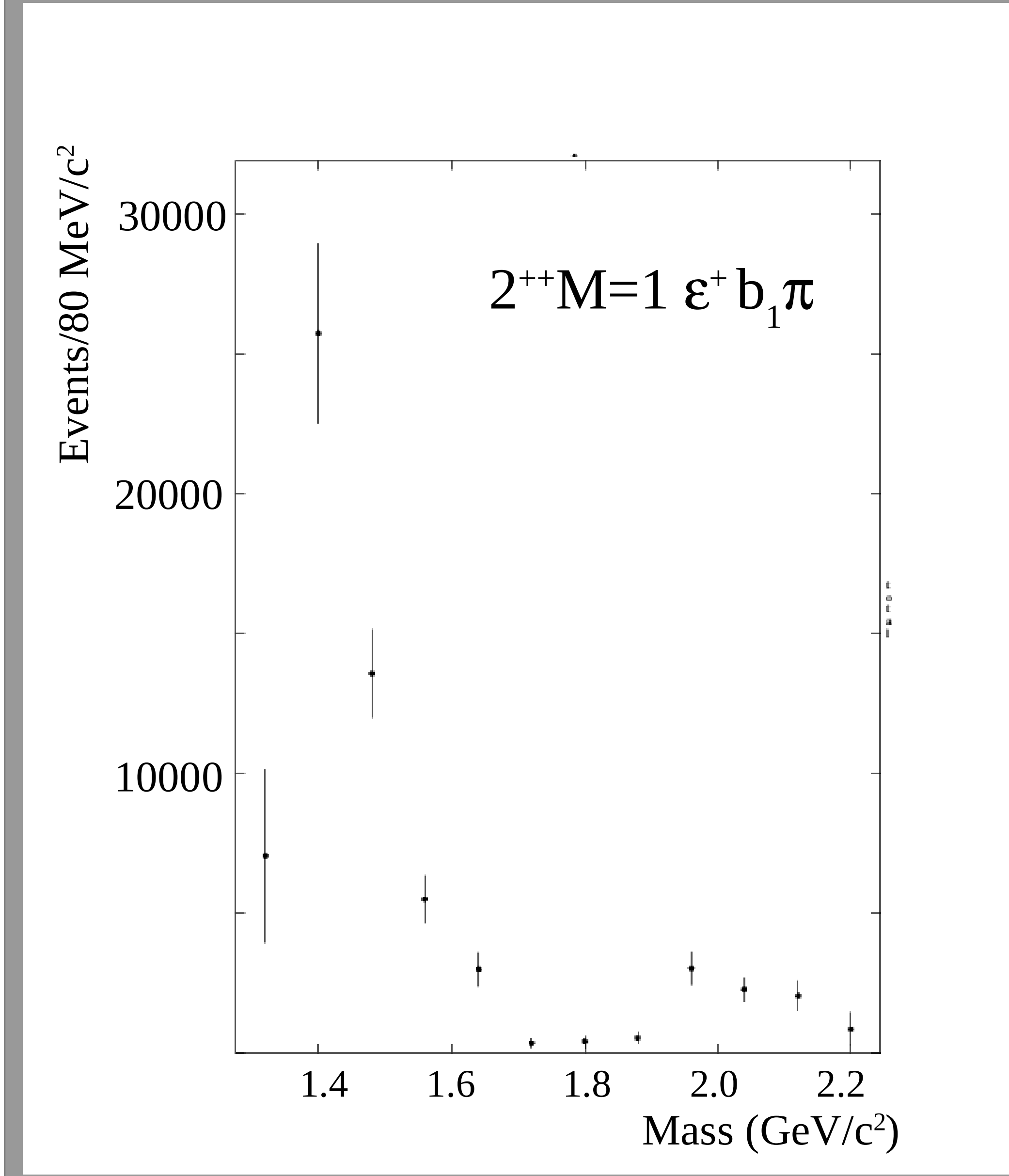
E852 (1995) $\pi^- p \rightarrow \eta \pi^+ \pi^- \pi^- p$

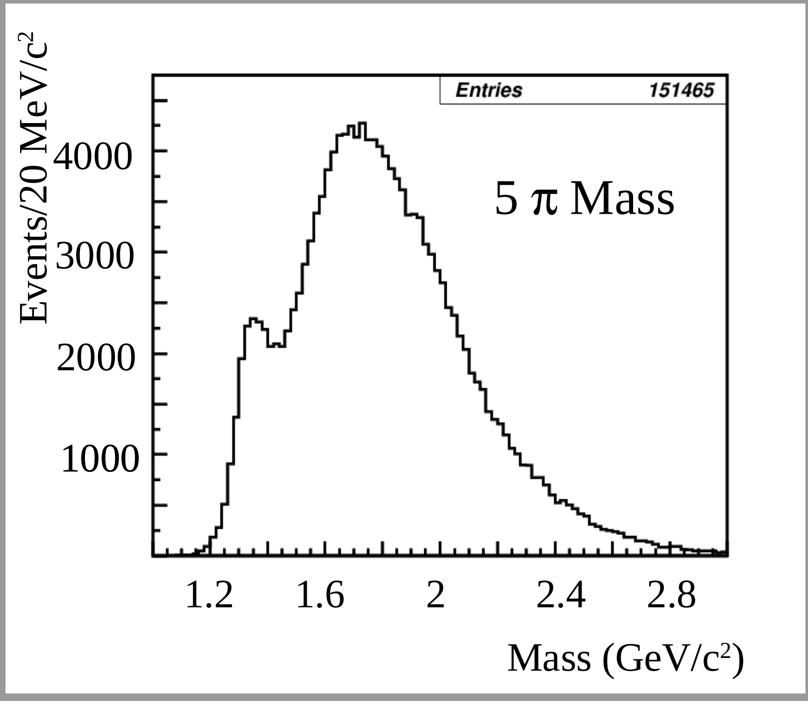
Partial Wave Analysis Results:

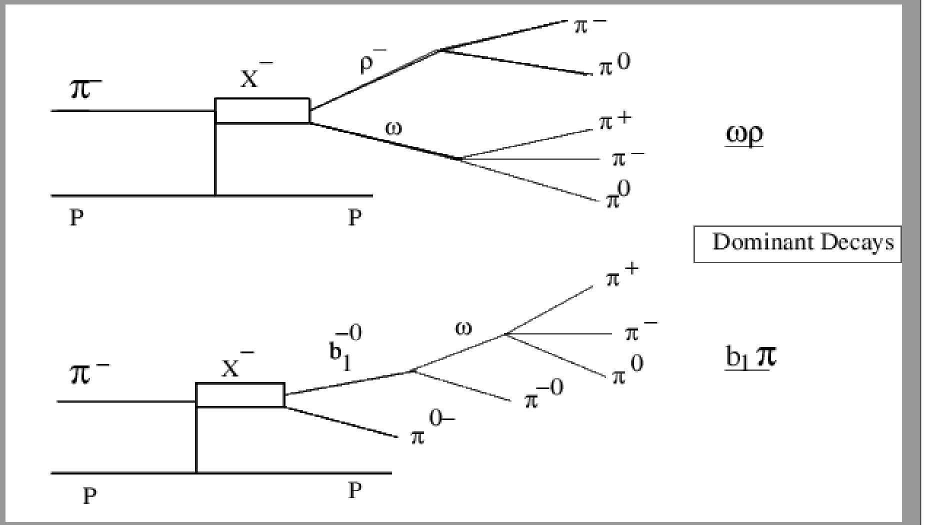
Wave ($J^{PC}M^{\varepsilon}$ decay L)	Mass (MeV/c^2)	Γ (MeV/c^2)
$1{+}{+}0^+ f_1 \pi P$	1714 (fixed) 2096 +/-17	308 (fixed) 451 +/- 41
$2{-}{+}0^+ f_1 \pi P$	1676 (fixed) 2003 +/- 88 2460 +/- 328	254 (fixed) 306 +/- 132 1540 +/- 1214
$1{-}{+}1^+ f_1 \pi S$	1709 +/- 24 2001 +/- 30	403 +/- 80 333 +/- 52



E852 (1995) $\pi^- p \to \omega \pi^0 \pi^- p$ 150,000 Events







E852 $\pi^- p \rightarrow \omega \pi^0 \pi^- p$ Partial Waves

$\mathbf{b_1}\pi(I^G = 1^-)$		
L	J^{PC}	M^ϵ
0	1^{-+}	1^+
	1^{-+}	1^-
	1^{-+}	0^-
1	1^{++}	0^+
	1^{++}	1^+
	2^{++}	1^+
	2^{++}	0^-
2	2^{-+}	0^+
	2^{-+}	1^-
	2^{-+}	1^+
3	2^{++}	1^+
	4^{++}	1^+

$\omega\rho(I^G = 1^-)$			
L	**S**	J^{PC}	M^ϵ
0	1	1^{++}	0^+
	2	2^{++}	0^-
	2	2^{++}	1^+
1	1	0^{-+}	0^+
	1	2^{-+}	0^+
	1	2^{-+}	1^-
	2	2^{-+}	0^+
	2	2^{-+}	1^+
2	2	1^{++}	0^+
	2	1^{++}	1^+
	2	3^{++}	0^+
	2	4^{++}	1^+
3	1	2^{-+}	0^+

Tested and rejected:

$\rho(1450)\,\pi$

$a_1(1260)\,\sigma$

$a_2(1320)\,\sigma$

Included:

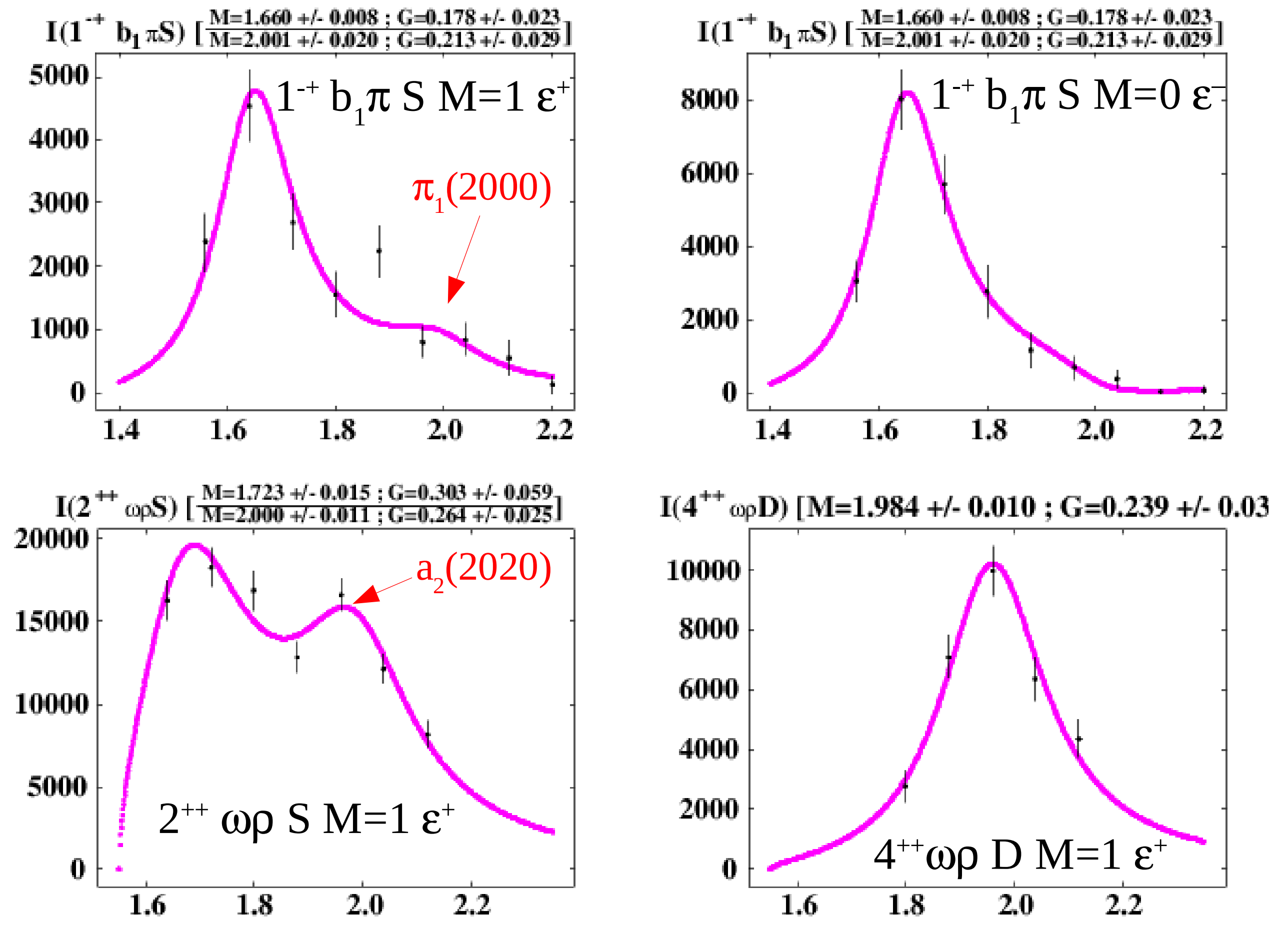
$\rho_3(1690)\pi$ $3^{++}0^+$

+ incoherent isotropic background

27 waves in fit

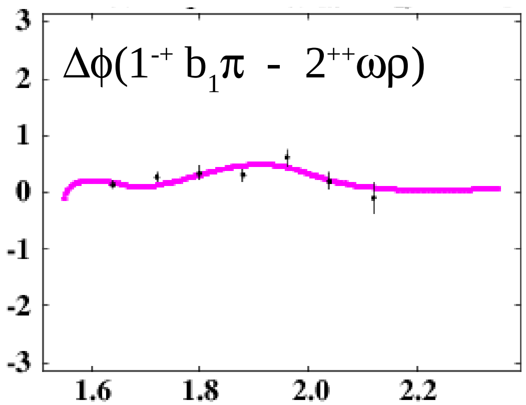
E852 1995 $\pi^- p \rightarrow \omega \pi^0 \pi^- p$

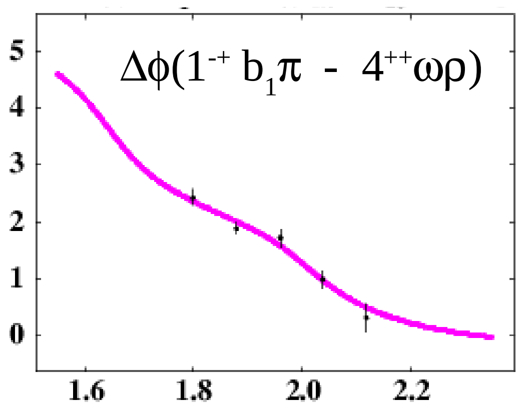
Intensity

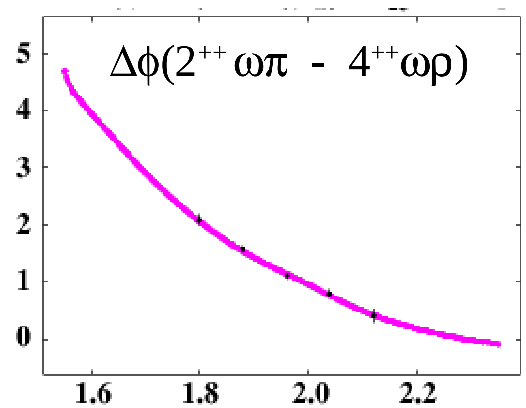


E852 1995 $\pi^- p \rightarrow \omega \pi^0 \pi^- p$

Phases Differences







$$\frac{\chi^2}{DOF} = \frac{32.97}{25} = 1.32$$

E852 (1995) $\pi^- p \rightarrow \omega \pi^0 \pi^- p$

Partial Wave Analysis Results:

Wave	Mass(MeV/c^2)	Width (MeV/c^2)
$1^{-+}1^+ b_1 \pi S$	1687 ± 11	206 ± 28
	2028 ± 19	214 ± 33
$2^{++}0^+ \omega \rho S$	1753 ± 16	279 ± 43
	2019 ± 9	232 ± 22
$4^{++}0^+ \omega \rho D$	1995 ± 10	208 ± 26

E852 $\pi^- p \rightarrow \omega \pi^0 \pi^- p$

Barnes, Close, Page, & Swanson PRD55:4157-4188 (1997)

$\pi_2(1670) \rightarrow \omega\rho$ $\pi_2(1900) \rightarrow \omega\rho$

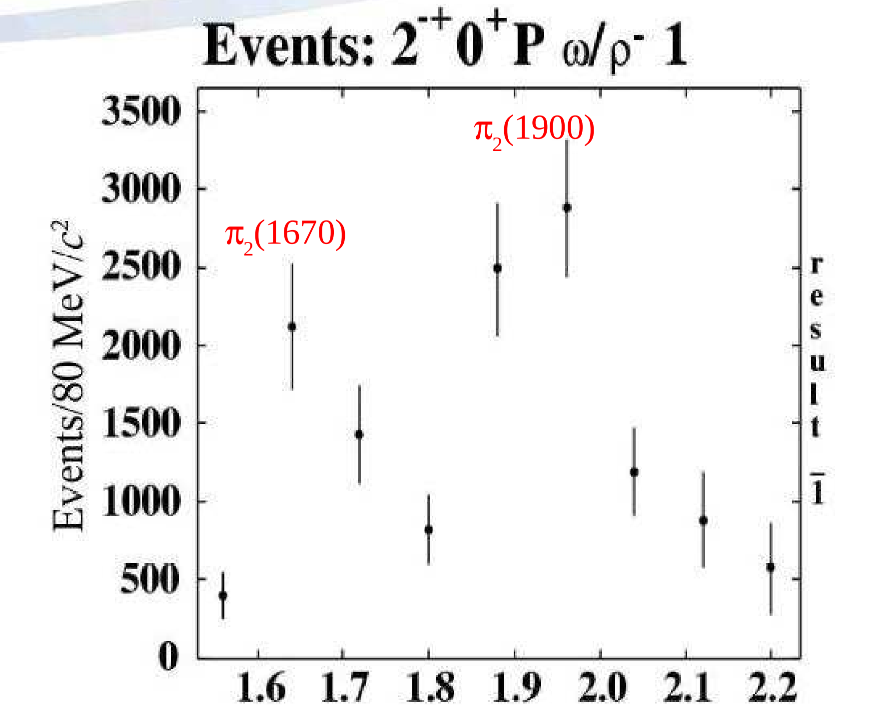


TABLE V. Partial widths of 1D and hybrid $\pi_2(1800)$ states.

	$\rho\pi$	$\omega\rho$	$\rho_R\pi$	$b_1\pi$	$f_0\pi$	$f_1\pi$	$f_2\pi$	K*K	total
$\pi_{2(1D)}(1800)$	162.	69.	0.	0.	1.	5.	86.	49.	372.
$\pi_{2(H)}(1800)$	8	0	5	15	1	0	50	1	80

$\pi(1800) \rightarrow \omega\rho$

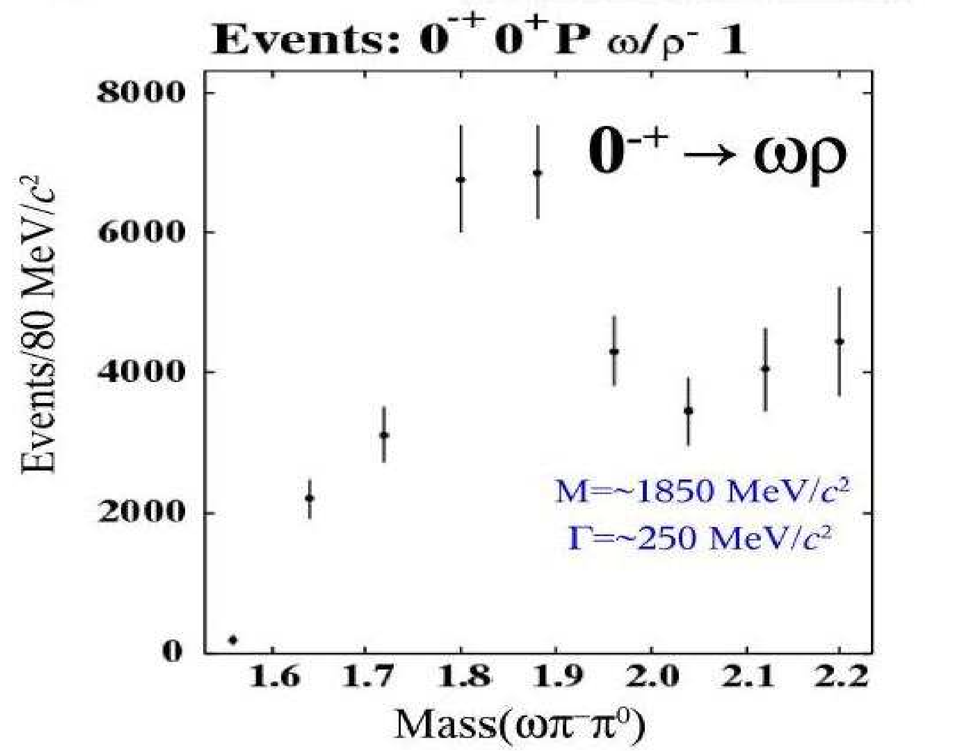
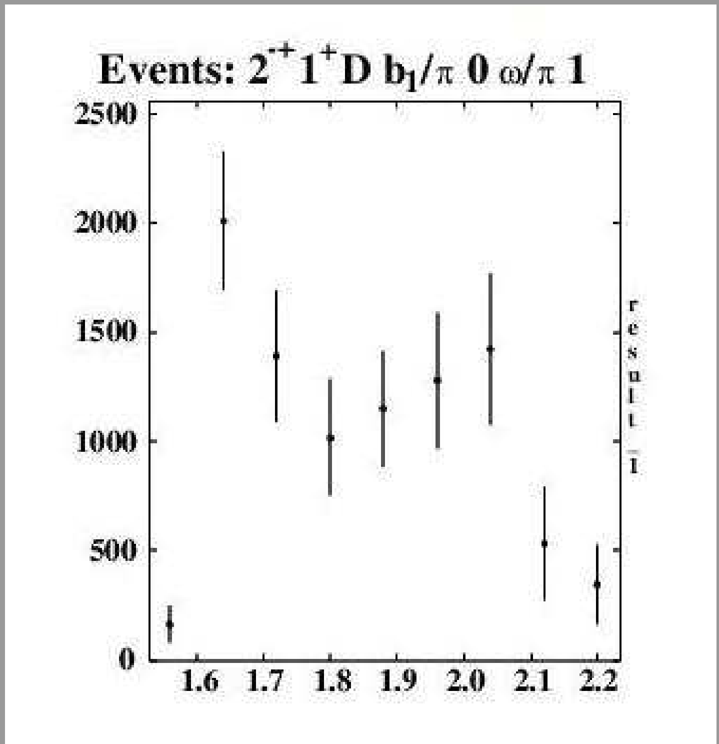
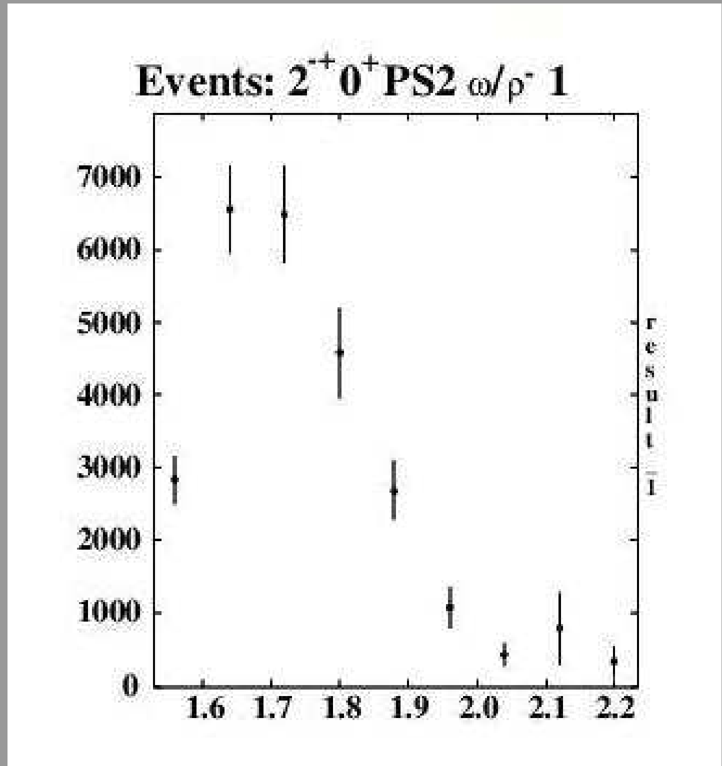


TABLE III. Partial widths of 3S and hybrid $\pi(1800)$ states.

	$\rho\pi$	$\rho\omega$	$\rho(1465)\pi$	$f_0(1300)\pi$	$f_2\pi$	K*K	total
$\pi_{3S}(1800)$	30.	74.	56.	6.	29.	36.	231.
$\pi_H(1800)$	30	0	30	170	6	5	≈ 240

${}^3P_0$ decay of the $\pi_2(1670)$



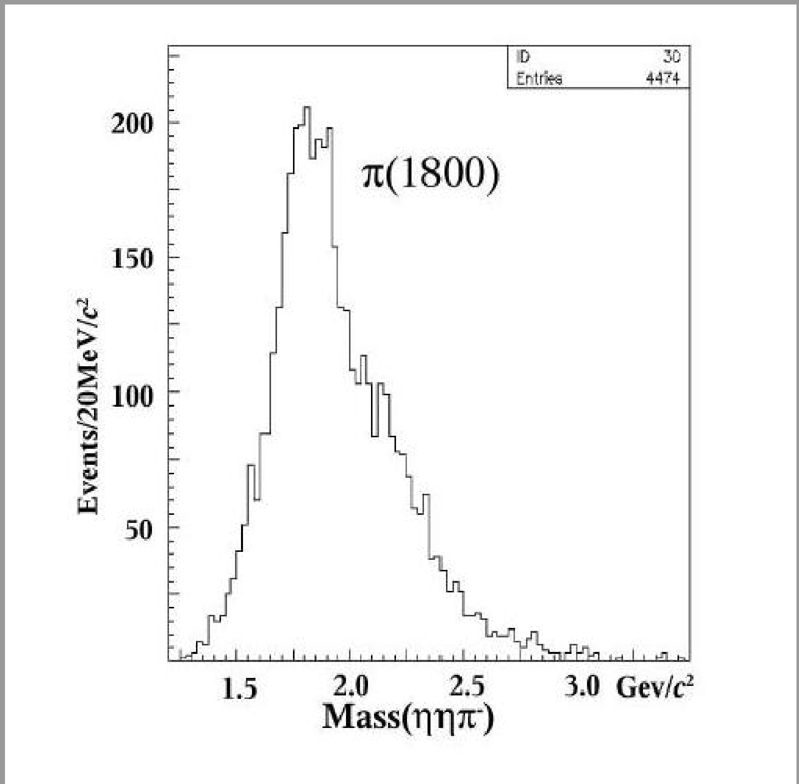


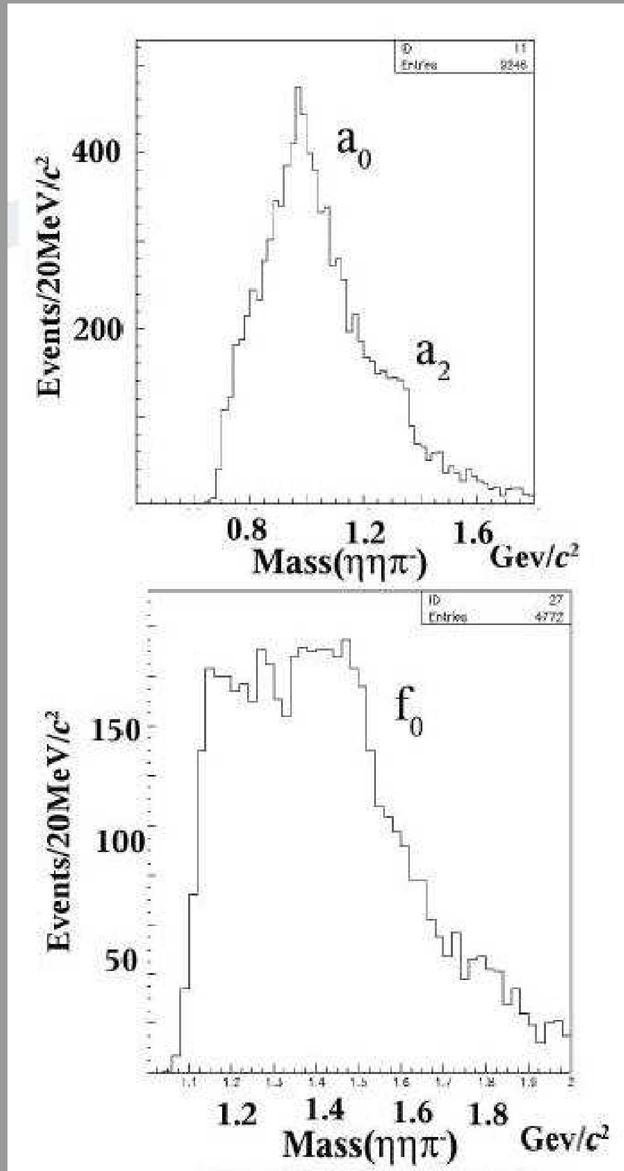
$\pi_2(1670) \not\rightarrow b_1(1235)\pi \quad (S=0) \rightarrow (S=0)$

${}^3P_0 \qquad (S=1)\vec{\sigma} \bullet \vec{p}$

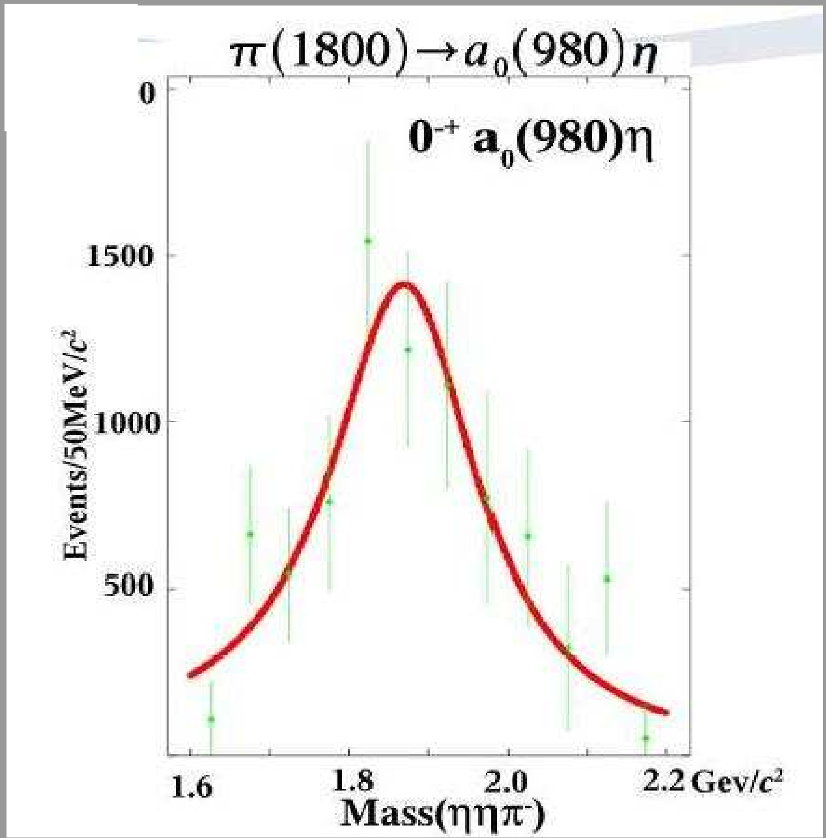
$\pi_2(1670) \not\rightarrow \rho\,\omega \;\; ({}^5F_2) \qquad (S=0) \rightarrow (S=2)$

E852 $\pi^- p \to \eta\eta\pi^- p$





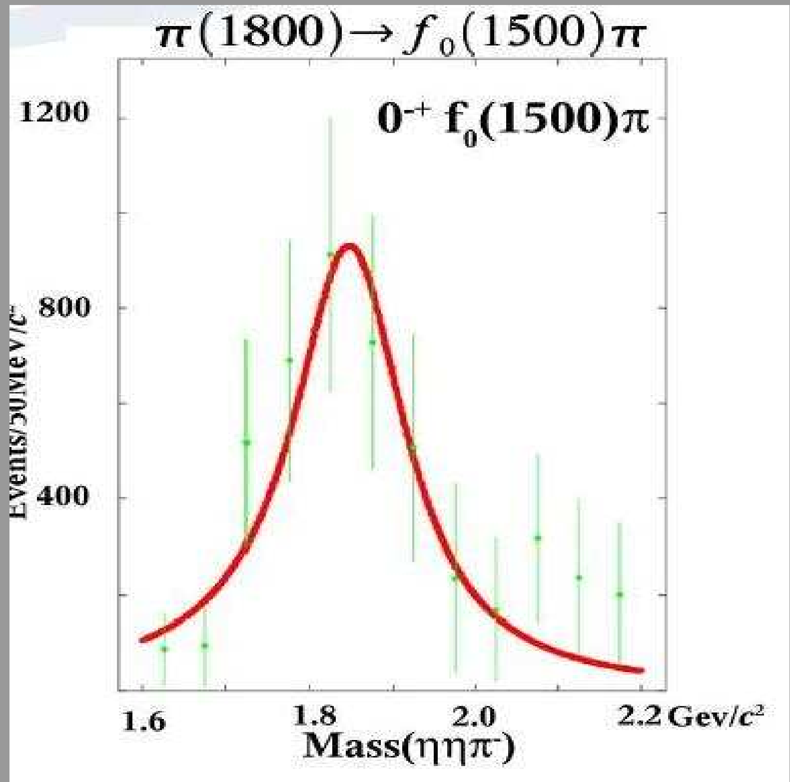
E852 $\pi^- p \rightarrow \eta\eta\pi^- p$ $\pi(1800)$



$\pi(1800) \rightarrow a_0(980)\eta$

$M = 1884 \pm 19_{stat}\, MeV/c^2$

$\Gamma = 222 \pm 39_{stat}\, MeV/c^2$



$\pi(1800) \rightarrow f_0(1500)\pi$

$M = 1862 \pm 24_{stat}\, MeV/c^2$

$\Gamma = 166 \pm 46_{stat}\, MeV/c^2$

SU(3)$_{\text{flavor}}$ Symmetry

$$8 \otimes 8 = 27 \oplus 10 \oplus \overline{10} \oplus 8_1 \oplus 8_2 \oplus 1$$

Lipkin, PL**B196**, 245 (1989)

$$J^{PC} = 1^{-+} \quad \bar{q} G q \not\to \eta\pi, \eta'\pi$$

Chung & Klempt: (submitted to Phys.Lett. B)

$$if \; X_{10 \oplus \overline{10}} \to \eta_8 \pi \;\Rightarrow\; X \not\to \rho\pi$$

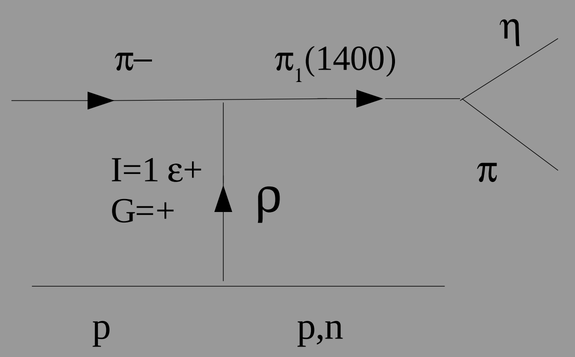
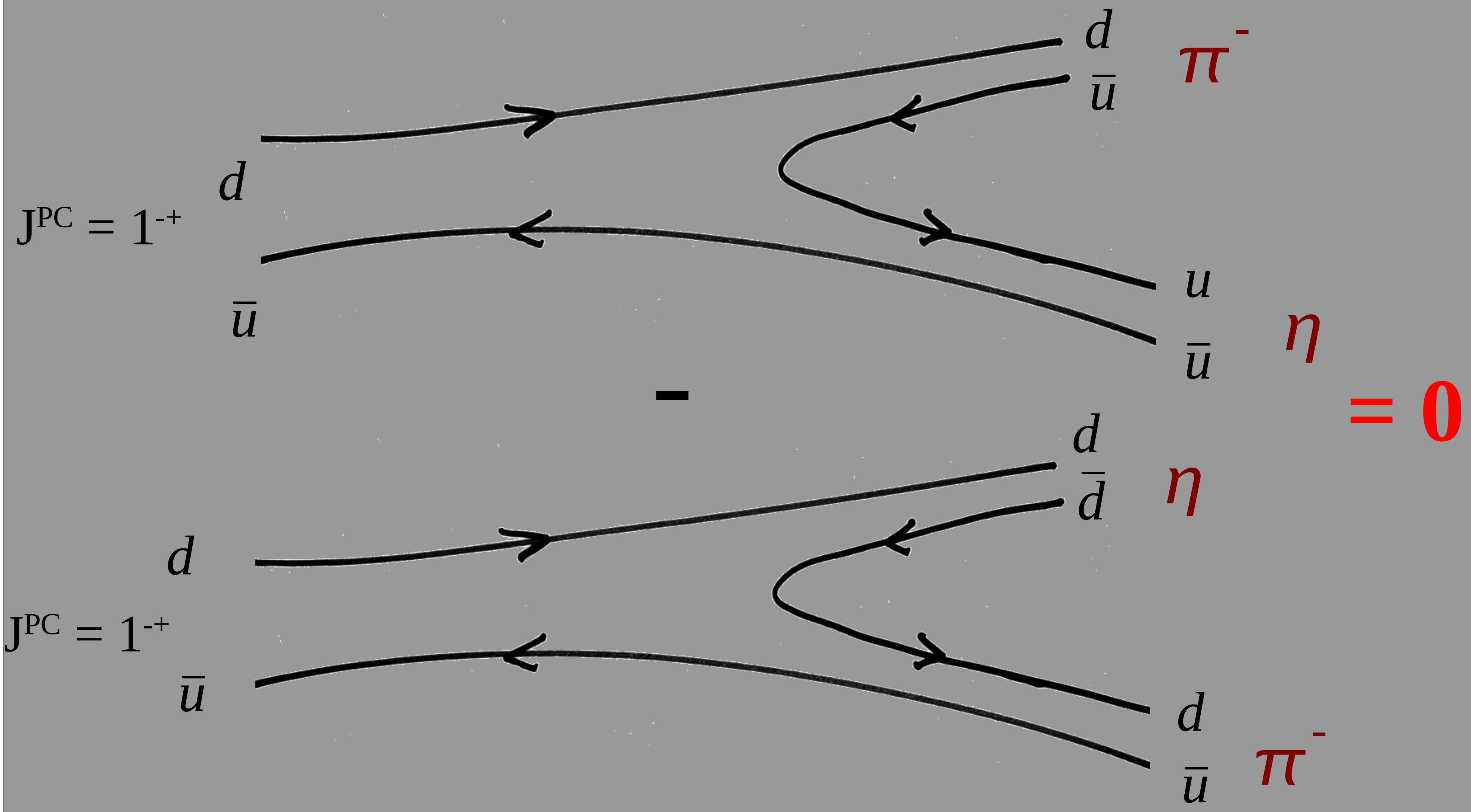


Table II: $SU(3)$ Multiplets and their Composition		
$SU(3)$ Multiplet	J^{PC} or J^P	Composition
Singlet ($\mathbf{1}$)	even^{++}	$q\bar{q}$, $q\bar{q}+g$, $q\bar{q}+q\bar{q}$
Symmetric Octet ($\mathbf{8_1}$)	even^{++}	$q\bar{q}$, $q\bar{q}+g$, $q\bar{q}+q\bar{q}$
Antisymmetric Octet ($\mathbf{8_2}$)	odd^{--}	$q\bar{q}$, $q\bar{q}+g$, $q\bar{q}+q\bar{q}$
multiplet $\mathbf{20}$ ($\mathbf{10} \oplus \overline{\mathbf{10}}$)	odd^{-}	$q\bar{q}+q\bar{q}$ (14 strange states)
	odd^{-+}	$q\bar{q}+q\bar{q}$ (3 non-strange states)
	odd^{--}	$q\bar{q}+q\bar{q}$ (3 non-strange states)
Multiplet 27	even^{++}	$q\bar{q}+q\bar{q}$

Chung,Klempt, and Korner Eur.Phys.J.A15, 539 (2002)

$SU(2)_{flavor}$ (Isospin) Symmetry

Lipkin, Phys.Lett. B219, 99 (1989)



Summary and Conclusions

π_1(1400): 'First' $J^{PC}=1^{-+}$ Exotic Meson: M ~ 1400 MeV/c^2, Γ ~ 340 MeV

$q\bar{q}q\bar{q}$?

π_1(1600): Seen now in $\rho\pi$, $\eta'\pi$, $f_1(1285)\pi$, $b_1(1235)\pi$

M ~ 1600 MeV/c^2, Γ ~ 340 MeV gluonic hybrid?

ε+ ε-?

NEW: π_1(2000) : Seen in 'preferred' modes $f_1(1285)\pi$ and $b_1(1235)\pi$

π(1800): $\omega\rho$ decay mode indicates radial excitation (2 states?)

a_1(1700): Radial excitation from S/D ratio

π_2(1900): $\omega\rho$ decay indicates radial excitation

However, $a_2(1320)\eta/f_1(1285)\pi$ indicates hybrid interpretation (2 states?)

Future

$\pi^+\pi^-\pi^-$: 20X the statistics from the 1995 data run

t-evolution of many states

$\eta' \pi^0$ information on the production (exchange) process

K decay modes